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PRECIPITATION IN THE GREAT PLAINS

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The revision of the general table of the Weather Bureau Climatological Data according to sections rather than on a State-wide basis, effective January 1, 1936, presented an excellent opportunity to reexamine precipitation data for the Great Plains section.

It was possible to extend the data to a uniform 50-year period from 1887 to 1936, in those cases where the original data did not cover the above period. Extrapolation of data was performed cautiously and extensions were made with care, but it must be realized that data for some early periods are based on fewer stations than in later years. It is believed, however, that the data are homogeneous as near as it is practicable to make them and comparisons drawn therefrom may be accepted as accurate to a close approximation.

Precipitation data have been computed for long-time trends for individual stations in the Great Plains region and several trend studies have been made on a State-wide basis. The subdivision of the six major States of the area, from North Dakota southward, gave an opportunity to study the climatic aspect of various sections separately.

An interesting feature of the study is the inadvertent checking of the uniformity of the subdivisions from a climatological viewpoint. It is well known that the natural vegetation and soils of the Great Plains do not conform to the arbitrary divisions of the States. A casual comparison of the natural vegetation map with the soil type map (1) indicates a close relationship between them. What could be more natural than to assume a causal relationship with the climate? Thornthwaite (2) develops this more fully and an examination of his maps of climatic years indicates a close relationship.

The actual eastern boundary of the Great Plains has been variously described and is uncertain. Numerous investigators place it at varying intervals from the eastern limit of the dark-brown soils, the extent of the short grass, or the average position of the 20-inch annual rainfall isohyetal. In a report to the President, the Great Plains committee (3) includes practically all of North and South Dakota and Nebraska, roughly two-thirds of Kansas, one-half of Oklahoma, and the northwestern third of Texas. With these variously suggested boundaries, it is very difficult to adjust climatic boundaries to conform as closely as practicable to logical limits.

It is also difficult to secure the exact climatic characteristics that should be used in differentiating regions. Equal annual rainfall has been considered as typifying certain regions, while Thornthwaite (*loc. cit.*) has developed rainfall indices based on rainfall-evaporation resultants. The latter is undoubtedly more significant than any single climatic factor, but there are certain

phases of the problem, as brought out by him and other authors, that should be considered. For example, it is noted by Kincer (4) that in considerable areas from 55 to more than 65 percent of the warm season precipitation



FIGURE 1.—Subdivisions of States in the Great Plains region and various natural boundaries.

falls at night. While this may not be significant from the viewpoint of total accumulations, the occurrence at a time of minimum evaporation is highly significant from the standpoint of effective precipitation.

Kincer shows also (5) that less than 10 percent of the annual precipitation in the Great Plains occurs during the winter months (December–February), and that from 40 to over 50 percent occurs during the summer months (June–August). Included in the same study are a number of charts illustrating the average number of days with precipitation in varying amounts from 0.01 inch to over 2.00 inches. It is noteworthy that in the Plains area the number of days with precipitation from 0.01 to 0.25 inch vary from 40 to 80 days and mostly less than 1 with precipitation over 2.00 inches. And on still another page is a chart showing the percentage of years with 30 consecutive days or more without 0.25 inch of rainfall in 24 hours from March to September, inclusive. This is probably one of the most significant of the various charts as regards the Great Plains. The chart indicates that practically all of the Plains has such a dry period 70 percent of the time, or 7 years in 10, on the average, while the western boundary usually has such a dry period 90 to 100 percent of the years.

These significant features all combine to justify the inclusion by Jefferson (6) of this region in the semi-arid zone. Ward (7), however, includes much of the Great Plains area in the "Eastern" type, including in his classification most of the Great Plains area from eastern North Dakota southward roughly to central Texas. This division is more or less arbitrarily made on the 20-inch mean annual isohyetal and the 2,000-foot contour line. Thornthwaite (*loc. cit.*) also includes roughly the same area as Jefferson in the semi-arid zone.

All these climatic subdivisions, however, only agree approximately with the natural vegetation and soil province distribution. If we are to accept the theory that natural vegetation and soil are a result of long-time climate, or rather an accumulation of weather, it is quite possible that certain phases have not been included in the climatic studies. It may well be that some weather elements, such as distribution and intensity of rainfall, should be considered. Thornthwaite (8) has already shown in Oklahoma that certain patterns of intensities do occur and that the erosion of soils may be directly related to different intensities of rainfall.

The frequency of certain amounts of precipitation has always had a bearing on its effectiveness. It is axiomatic that a large number of slow, relatively gentle rains are more favorable for agriculture than a single heavy downpour. It is also well known that precipitation, in general, represents what is known as a skewed distribution when long-time averages of amounts are considered. The median of an array of precipitation data is ordinarily found to be somewhat less than the arithmetic mean. Also, the mode, or most frequent amount, is generally somewhat less than the mean.

Ordinarily, for well-distributed rainfall, such as in the eastern United States, a quite even distribution of the data is found, with the median only slightly below the mean and the mode slightly below the median. This frequency distribution might well be termed a "normal" distribution. In regions such as the Great Plains, however, the greater frequency of dry years or seasons distorts the curve considerably, with the median appearing an appreciable distance below the mean and the mode quite a ways below the median. This study of precipitation in the Great Plains has verified these characteristic distributions in most instances. Occasionally the distribution was found to be very much distorted by a bimodal phase, particularly noticeable in the fall months in western sections.

For the purposes of this study, the States were used exactly as subdivided in the table mentioned at the beginning of the article—Figure 1 shows the subdivisions. The States of Colorado, New Mexico, Minnesota, Iowa, Missouri, Arkansas, and Louisiana were not divided, and those from North Dakota southward to Texas were considered as the Great Plains proper, although the eastern portions of the tier to the westward should properly be considered.

As indicated before, the subdivisions were also considered in their relation to a logical division of the Plains. It becomes readily apparent from the map that the divisions have no direct relation to either vegetative, climatic, or soils classification. This also becomes evident in considering the data obtained from the study.

As an aid in handling the data, all rainfall data were reduced to percentages of the 50-year averages. These percentage figures were then arrayed in frequency distributions as follows: Under 50 percent; 50 percent to 69 percent; 70 percent to 89 percent; 90 percent to 109 percent; 110 percent to 129 percent; 130 percent to 149 percent; and 150 percent and over. Under this array, the midpoints of the groups fall in the following manner: 40 percent, 60 percent, 80 percent, 100 percent, 120 percent, 140 percent, and 160 percent, assuming, of course, that the midpoints of the end groups fall as specified. This is, of course, an erroneous assumption, but for the purpose of discussion they may be used as indicated. Also, no attempt has been made to verify the assumption of the midpoints of the groups falling as indicated.

Furthermore, it is realized that the use of frequency distributions for as few data as 50 is liable to errors of greater or less magnitude. However, the indicated frequencies are based on a larger period of record than has heretofore been available. The percentages determined from these distributions should not vary materially for some time to come, as a 50-year record is usually considered fairly satisfactory for climatological purposes.

Figure 2 shows the average spring, summer, autumn, and March–August precipitation for the 50-year period 1887–1936. The regular decrease in amount from east to west is indicated clearly, also the marked lack of spring precipitation in western Texas and New Mexico.

Table I shows the percent of the years with frequencies of seasonal precipitation as indicated. One of the most striking features of this table is the lack of unusually low percentages in the summer in western Texas. The frequencies in this group are also low in the eastern States of the area. It is natural that the percentages for the longer periods should be closer to the normal, hence the reductions in number of extreme percentages in the March–August data. The percentages are low in both extremes in this group, but are significant in eastern Montana and some western portions of the central group of States. An unusual feature of the fall tabulation is the high percentage of the extremely low precipitation in western Montana.

Figure 3 shows the rainfall variability as measured by the percentage of years with precipitation more than 30 percent greater or less than normal. It is believed to be a valuable indicator of the frequency of extremes of rainfall, including as it does those falls of greater than 130 percent and less than 70 percent. Within these figures, of course, considerable variation in crop conditions may occur, depending on other weather items than precipitation, but if the major portions of precipitation of an area occur within these limits it may be safely concluded that precipitation is quite stable for agriculture.

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The variability of spring precipitation (March-May), is based on a 50 year record. It varies widely in more than one-third of the years in most of the region and nearly half the years in central North Dakota. Western Texas shows conspicuously as an area of wide precipitation fluctuations in this season of the year, with the percentage 54, or well over half the years.

Similar conditions are shown for the summer months (June-August). During this season precipitation becomes more stable in many sections, markedly so in western Texas, New Mexico, and Colorado. A similar percentage decline is noted in Nebraska, but marked increases appear in central and western Montana and in Oklahoma.

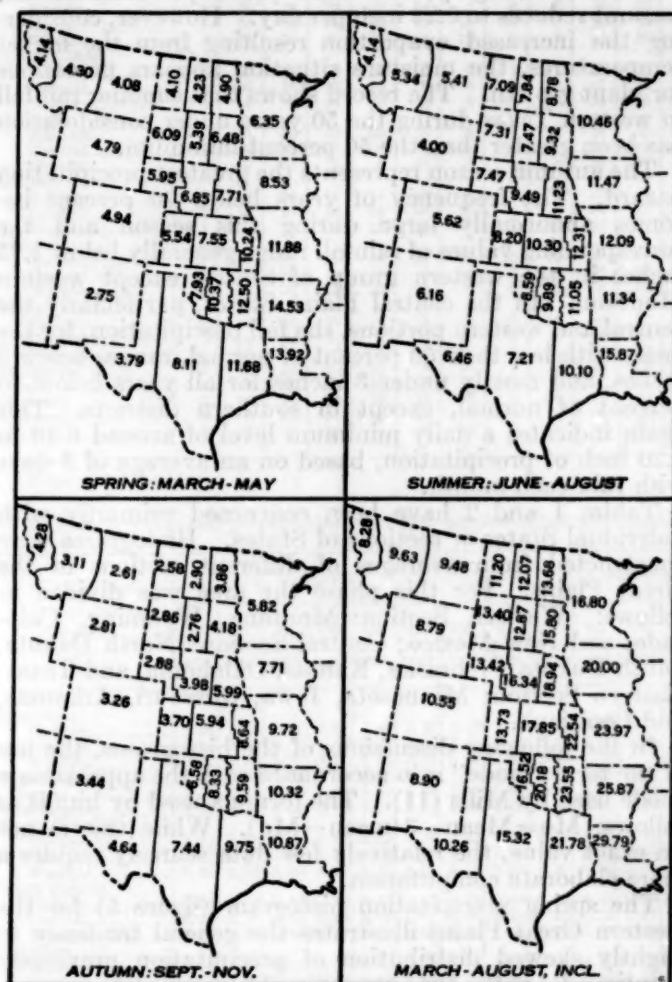


FIGURE 2.—Average precipitation.

For the autumn season (September-November), variations become unusually marked during this season, rising remarkably in practically all sections. The fluctuations become particularly noteworthy in western Oklahoma, and from western Kansas northward through Nebraska and the central Dakotas. There is a slight tendency to more stable precipitation in central Montana and Missouri.

The period March-August, inclusive, covers the season of growth for most crops. It is natural for smaller percentages to be recorded, as previously noted, but significant values are shown in several districts. Variations are marked in central Montana, western South Dakota, western Nebraska, and central and western Texas. An unusual feature of this chart is the abnormally large percentage shown in eastern Oklahoma. Quite stable pre-

cipitation is indicated for Colorado, probably due to the inclusion of data from all stations in the State average.

Figure 4 is a companion to figure 3, showing rainfall variability under droughty conditions. It indicates the percent of the years with precipitation less than 70 percent of normal, and is based on the assumption that such moisture conditions may be considered as approaching the minimum necessary for plant growth, particularly in western portions of the Plains where the rainfall is normally light.

Large drought percentage frequencies are shown in the western Dakotas, western Kansas and Oklahoma, and western Texas and New Mexico. Rather stable precipi-

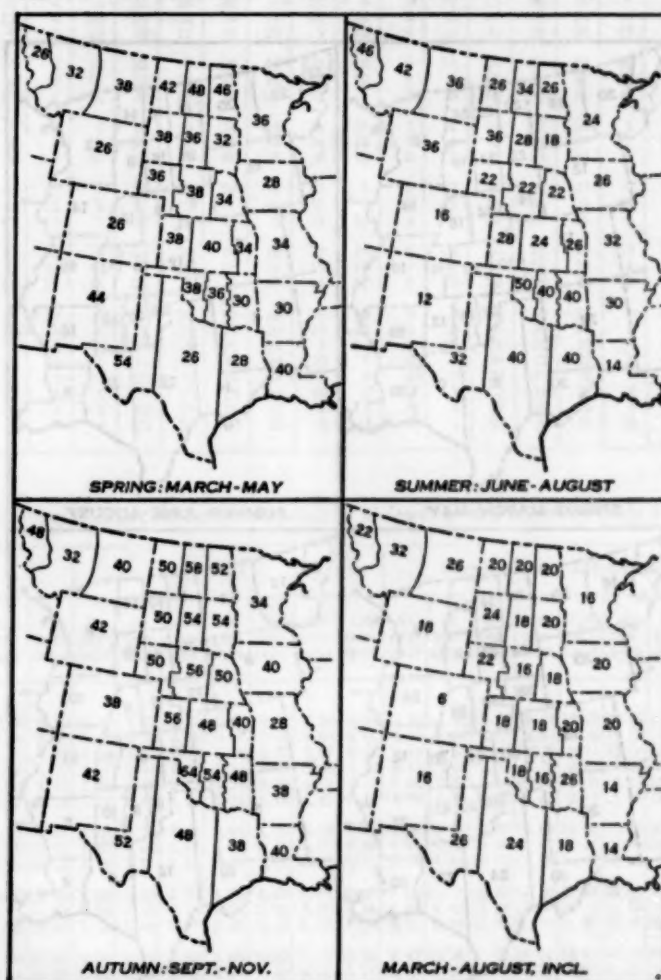


FIGURE 3.—Rainfall variability, percent of time precipitation varied 30 percent, or more, from normal.

tation is indicated in Arkansas, Colorado, Wyoming, western Montana, and central and eastern Texas. The figures for the first three States above may be due, again, to use of State averages rather than by sections.

The dry year variability for the summer is evident. Again, marked variation is indicated in Oklahoma, particularly the western portion, while quite marked deviations are noted in Texas and Montana. Rather remarkable stability is indicated in Colorado and New Mexico, and as this cannot be due entirely to State averages, it indicates a more dependable moisture condition for summer crops than in some sections farther east.

There is shown a marked increase in frequency of dry years in the autumn; this is particularly marked in western

Texas, New Mexico, and in Kansas and Nebraska. Approximately 3 years out of 10 are dry in the fall in most of the central Plains area; and in some sections, notably western Oklahoma, the count rises to nearly 4 years out of 10.

The warm season (March to August) shows the same general decline in values as the previous one for the same period. Percentages are less, compared with individual seasons, but significant tendencies to dry seasons appear in western Kansas and Nebraska, as well as in central and western Texas. Central and western Montana also show relatively large percentages, but marked stability is again shown in Colorado and Louisiana. The latter State usually has adequate precipitation for any needs.

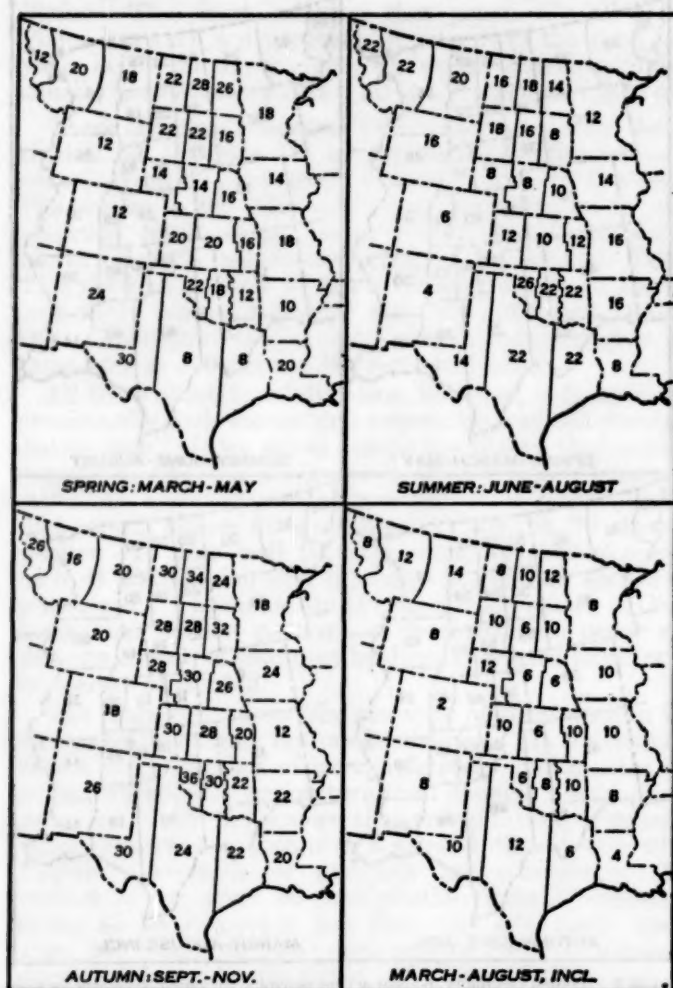


FIGURE 4.—Rainfall variability, percent of time with precipitation less than 70 percent of normal.

Before turning to frequency histograms of the various sections it may be well to consider table 2. This table shows the rainfall values corresponding to the lower values of the groups. Thus for western Texas in spring 50 percent of the mean value is 1.90 inches. Turning to table 1, 10 percent of all years are below 50 percent of the mean precipitation for western Texas in spring. Thus, 1 year in 10 will have precipitation below 1.90 inches in spring. This reduces to approximately 0.63 inch of precipitation a month. As the average number of days with 0.01 inch or more in western Texas ranges from 3 to 7, with an average of 5, it will be readily seen that average

individual rains under the above conditions do not ordinarily exceed 0.13 inch. Under normal conditions in this region, with relatively warm days and high evaporation, such rains are scarcely sufficient to support vegetation, unless it be a highly drought-resistant type. Assuming for example, an average rainfall of 0.25 inch on 5 days a month, or monthly totals of 1.25 inches, the spring precipitation would then be 3.75 inches. For agricultural purposes this amount would leave little to spare yet it will be seen from tables 1 and 2 that 74 percent of the years in western Texas have less than 3.75 inches in spring.

The situation is somewhat better in summer as the average rainfall in this region is then 6.46 inches, or 2.15 per month—roughly, 0.43 inch per day. Half of this amount reduces to 0.22 inch per day. However, considering the increased evaporation resulting from the higher temperatures, the moisture situation appears precarious for plant growth. The record shows that summer rainfall in western Texas during the 50 years under consideration has been greater than the 50 percent minimum.

The autumn season represents the greatest precipitation hazard. The frequency of years below 70 percent becomes abnormally large during this season and the corresponding values of rainfall range generally below 1.75 inches in the western group of States, except western Montana. In the central Plains States, particularly the central and western portions, the fall precipitation, for the years with less than 50 percent of normal, ranges below 2 inches, and mostly under 3 inches for all years below 70 percent of normal, except in southern districts. This again indicates a daily minimum level of around 0.10 to 0.20 inch of precipitation, based on an average of 5 days with rain each month.

Tables 1 and 2 have been concerned primarily with individual States or sections of States. Histograms were constructed from averages of different sections of the Great Plains. For this phase the area was divided as follows: Western Section: Montana, Wyoming, Colorado, and New Mexico; Central Section: North Dakota, South Dakota, Nebraska, Kansas, Oklahoma, and Texas; Eastern Section: Minnesota, Iowa, Missouri, Arkansas, and Louisiana.

In the following discussions of the histograms, the use of the term "mode" is in accordance with the approximate mode used by Mills (11). The formula used by him is as follows: $Mo = Mean - 3(mean - Md)$. While this is not an exact value, the relatively few data scarcely require a more elaborate computation.

The spring precipitation histogram (figure 5) for the western Great Plains illustrates the general tendency to slightly skewed distribution of precipitation previously mentioned, with the approximate mode 93 percent. The central Great Plains histogram presents a markedly skewed diagram, with the general tendency leaning heavily toward the lower percentages. In this diagram the mode is 89 percent, or well toward the lower part of the diagram. The great frequency of lesser amounts is marked in the central Great Plains, where much of the spring precipitation falls in less than normal amounts. The eastern sections revert back to a modified skewness, with the mode 94 percent.

Summer precipitation histograms for the Great Plains represent nearly a normal frequency distribution, with the modes for the western and central diagrams falling only 2 or 3 percent below the mean. Also for the eastern sections the mean, median, and mode practically coincide, representing as nearly a symmetrical frequency distribution as could be expected to obtain in unrelated data.

TABLE 1.—Percent of years with precipitation in frequencies shown

	Spring						Summer						Fall						March-August, inclusive						
	Under 50 percent	50-69 percent	70-89 percent	90-109 percent	110-129 percent	130-149 percent and over	Under 50 percent	50-69 percent	70-89 percent	90-109 percent	110-129 percent	130-149 percent and over	Under 50 percent	50-69 percent	70-89 percent	90-109 percent	110-129 percent	130-149 percent and over	Under 50 percent	50-69 percent	70-89 percent	90-109 percent	110-129 percent	130-149 percent and over	
Montana:																									
Eastern.....	10	8	28	18	16	8	12	2	18	16	24	24	12	4	10	10	16	28	16	14	6	4	10	14	40
Central.....	4	16	14	28	26	6	6	10	12	18	24	16	10	10	8	8	26	20	22	4	12	2	10	26	30
Western.....	0	12	22	34	18	12	2	6	16	18	28	8	12	12	18	8	14	20	18	12	10	0	8	34	22
Wyoming.....	2	10	28	20	26	14	0	4	12	24	20	20	16	4	6	14	26	18	14	12	10	0	8	22	40
Colorado.....	0	12	30	24	20	10	4	2	4	34	32	22	4	6	2	16	20	30	12	12	8	0	2	26	46
New Mexico.....	16	8	22	24	10	6	14	2	2	26	38	24	6	2	10	16	12	22	24	6	10	0	8	26	34
North Dakota:																									
Eastern.....	6	20	12	22	20	14	6	6	8	16	30	28	8	4	6	18	18	20	10	22	6	2	10	14	36
Central.....	12	16	12	20	20	10	10	4	14	12	38	16	12	4	10	24	12	14	16	14	10	2	8	30	24
Western.....	8	14	24	24	10	8	12	8	8	12	36	26	4	6	14	18	12	16	22	8	12	4	4	30	24
South Dakota:																									
Eastern.....	6	10	26	16	26	8	8	2	6	26	30	26	6	4	10	22	14	16	16	12	10	0	10	22	32
Central.....	6	16	16	18	30	6	8	2	14	20	28	24	4	8	16	12	18	14	14	10	16	4	2	26	36
Western.....	8	14	18	14	30	8	8	2	16	24	26	14	10	8	8	20	10	24	20	12	6	2	8	26	30
Nebraska:																									
Eastern.....	2	14	30	16	20	10	8	2	8	28	30	20	4	8	8	18	16	20	14	14	10	4	2	24	42
Central.....	8	6	34	22	6	14	10	2	6	26	42	10	8	6	10	20	20	8	16	14	12	2	4	30	34
Western.....	4	10	34	24	6	16	6	0	8	28	34	16	8	6	10	18	16	18	16	6	16	0	12	22	36
Kansas:																									
Eastern.....	0	16	24	28	14	12	6	6	6	26	20	4	10	8	12	22	20	18	12	8	2	8	18	38	24
Central.....	6	14	18	28	14	10	10	4	6	36	20	20	2	12	8	20	12	14	26	12	8	4	2	28	34
Western.....	4	16	18	22	12	10	8	2	10	26	28	18	12	4	8	22	20	16	8	12	14	2	8	22	34
Oklahoma:																									
Eastern.....	2	10	30	22	18	12	6	10	12	16	24	20	6	12	8	14	24	18	10	12	14	2	8	30	28
Central.....	4	14	24	28	12	6	12	4	18	22	20	18	6	12	12	18	10	26	10	12	12	2	6	24	36
Western.....	6	16	22	18	12	8	8	6	20	18	20	12	12	12	16	20	8	8	20	16	12	6	6	30	26
Texas:																									
Eastern.....	2	6	34	32	6	12	8	6	16	16	22	22	8	10	6	16	20	26	16	6	10	0	6	34	30
Central.....	2	6	40	22	12	8	10	2	20	16	26	18	10	8	6	18	20	22	10	12	12	0	12	26	30
Western.....	10	20	24	16	6	18	0	14	26	22	20	12	6	8	22	8	26	14	8	14	0	10	32	22	
Minnesota.....	2	16	22	32	10	8	10	2	10	20	28	28	12	0	4	14	12	38	16	10	6	0	8	20	42
Iowa.....	4	10	22	28	22	8	6	2	12	22	34	18	10	2	2	22	12	36	22	8	8	0	10	20	38
Missouri.....	0	18	18	30	18	10	6	2	14	16	38	14	12	4	6	6	28	22	22	10	6	2	8	22	34
Arkansas.....	2	8	32	24	14	18	2	2	14	20	30	20	8	6	4	18	16	28	18	8	8	0	8	22	36
Louisiana.....	2	18	20	26	14	12	8	2	6	20	40	26	6	8	8	12	28	20	12	6	14	0	4	34	28

Notes at end of table.

TABLE 2.—Normal precipitation (in 100-percent column), together with precipitation values corresponding to lower group limits of table 1.

	Spring							Summer							Fall							March-August, inclusive							
	50 per- cent	70 per- cent	90 per- cent	100 per- cent	110 per- cent	130 per- cent	150 per- cent	50 per- cent	70 per- cent	90 per- cent	100 per- cent	110 per- cent	130 per- cent	150 per- cent	50 per- cent	70 per- cent	90 per- cent	100 per- cent	110 per- cent	130 per- cent	150 per- cent	50 per- cent	70 per- cent	90 per- cent	100 per- cent	110 per- cent	130 per- cent	150 per- cent	
Montana:																													
Eastern.....	2.04	2.86	3.67	4.08	4.49	5.30	6.12	2.70	3.79	4.57	5.41	5.95	7.03	8.12	1.30	1.83	2.35	2.61	2.87	3.39	3.92	4.74	6.64	8.53	9.48	10.43	12.32	14.22	16.12
Central.....	2.15	3.01	3.87	4.30	4.73	5.59	6.45	2.67	3.74	4.51	5.34	5.87	6.94	8.01	1.56	2.18	2.80	3.11	3.42	4.04	4.66	4.82	6.74	8.67	9.63	10.59	12.52	14.42	
Western.....	2.07	2.90	3.73	4.14	4.55	5.38	6.21	2.67	2.90	3.73	4.14	4.55	5.38	6.21	2.14	3.00	3.85	4.28	4.71	5.56	6.42	4.14	5.80	7.45	8.28	9.11	10.76	12.46	
Wyoming.....	2.40	3.35	4.31	4.79	5.27	6.23	7.18	2.00	2.80	3.60	4.00	4.40	5.20	6.00	1.40	1.97	2.53	2.81	3.09	3.65	4.22	4.40	6.15	7.91	8.79	9.67	11.43	13.18	
Colorado.....	2.47	3.46	4.45	4.94	5.43	6.42	7.41	2.81	3.93	5.06	5.62	6.18	7.31	8.43	1.63	2.28	2.93	3.26	3.59	4.24	4.89	5.28	7.38	9.50	10.55	11.60	13.72	15.82	
New Mexico.....	1.38	1.92	2.48	2.75	3.02	3.58	4.12	3.08	4.31	5.54	6.10	6.78	8.01	9.24	1.72	2.41	3.10	3.44	3.78	4.47	5.16	4.45	6.23	8.01	8.90	9.79	11.57	13.35	
North Dakota:																													
Eastern.....	2.45	3.43	4.41	4.90	5.39	6.37	7.35	4.39	6.15	7.90	8.78	9.66	11.41	13.17	1.93	2.70	3.47	3.86	4.25	5.02	5.79	6.84	9.58	12.31	13.68	15.05	16.78	20.52	
Central.....	2.12	2.96	3.81	4.23	4.65	5.60	6.34	3.92	5.49	7.06	7.84	8.62	10.19	11.76	1.45	2.03	2.61	2.90	3.19	3.77	4.35	6.04	8.45	10.86	12.07	13.28	15.69	18.10	
Western.....	2.05	2.87	3.69	4.10	4.51	5.33	6.15	3.54	4.96	6.38	7.09	7.80	9.22	10.64	1.29	1.81	2.32	2.58	2.84	3.35	3.87	5.60	7.84	10.08	11.20	12.32	14.56	16.80	
South Dakota:																													
Eastern.....	3.24	4.64	6.03	6.48	7.13	8.42	9.72	4.66	6.52	8.39	9.32	10.25	12.12	13.98	2.09	2.93	3.76	4.15	4.60	5.43	6.27	7.90	11.06	14.22	15.80	17.38	20.54	23.76	
Central.....	2.70	3.77	4.85	5.39	5.93	7.01	8.08	3.74	5.23	6.72	7.47	8.22	9.71	11.20	1.38	1.93	2.48	2.76	3.04	3.59	4.14	6.44	9.01	11.58	12.87	14.16	16.78	19.30	
Western.....	3.04	4.26	5.48	6.09	6.70	7.92	9.14	3.66	5.12	6.58	7.31	8.04	9.50	10.90	1.43	2.00	2.57	2.86	3.15	3.72	4.29	6.70	9.38	12.06	13.40	14.74	17.42	20.10	
Nebraska:																													
Eastern.....	3.86	5.40	6.94	7.71	8.48	10.02	11.56	5.62	7.86	10.11	11.23	12.35	14.60	16.84	3.00	4.19	5.39	5.99	6.59	7.79	8.98	9.47	13.26	17.05	18.94	20.83	24.62	28.41	
Central.....	3.42	4.80	6.16	6.85	7.54	8.90	10.28	4.74	6.64	8.54	9.49	10.44	12.34	14.24	1.99	2.79	3.58	3.98	4.38	5.17	5.97	8.17	11.44	14.71	16.34	17.97	21.24	24.51	
Western.....	2.98	4.16	5.36	5.95	6.54	7.74	8.92	3.74	5.23	6.72	7.47	8.22	9.71	11.20	1.44	2.02	2.59	2.88	3.17	3.74	4.32	6.71	9.39	12.08	13.42	14.76	17.45	20.14	
Kansas:																													
Eastern.....	5.12	7.17	9.22	10.24	11.26	13.31	15.36	6.16	8.62	11.08	12.31	13.54	16.00	18.46	4.32	6.06	7.78	8.64	9.50	11.23	12.96	11.27	16.78	20.29	22.54	24.79	29.30	33.81	
Central.....	3.78	5.28	6.80	7.55	8.30	9.82	11.32	5.15	7.21	9.27	10.30	11.33	13.39	15.45	2.97	4.16	5.35	5.94	6.53	7.72	8.91	8.92	12.50	16.06	17.85	19.64	23.30	26.78	
Western.....	2.77	3.88	4.99	5.54	6.09	7.20	8.31	4.10	5.74	7.38	8.20	9.02	10.66	12.30	1.85	2.59	3.33	3.70	4.07	4.81	5.55	6.86	9.61	12.36	13.73	15.10	17.85	20.60	
Oklahoma:																													
Eastern.....	6.25	8.75	11.25	12.50	13.75	16.25	18.75	5.52	7.74	9.94	11.05	12.16	14.36	16.58	4.80	6.71	8.63	9.80	10.55	12.47	14.38	11.78	16.48	21.20	23.55	25.90	30.62	35.32	
Central.....	5.18	7.26	9.33	10.37	11.41	13.48	15.56	4.94	6.92	9.00	9.89	10.88	12.86	14.84	4.16	5.83	7.50	8.33	9.16	10.85	12.50	10.09	14.13	18.16	20.18	22.30	26.23	30.27	
Western.....	3.96	5.55	7.14	7.93	8.72	10.31	11.90	4.30	6.01	7.73	8.59	9.45	11.17	12.88	3.29	4.61	5.92	6.58	7.24	8.55	9.87	8.26	11.67	14.87	16.16	18.17	21.48	24.78	
Texas:																													
Eastern.....	5.84	8.18	10.51	11.68	12.85	15.18	17.52	5.05	7.07	9.00	10.11	11.11	13.13	15.15	4.88	6.82	8.76	9.75	10.72	12.68	14.62	10.89	15.25	19.60	21.78	23.96	28.31	32.67	
Central.....	4.06	5.68	7.30	8.11	8.92	10.54	12.16	3.60	5.05	6.49	7.21	7.93	9.37	10.82	3.72	5.21	6.70	7.44	8.18	9.67	11.16	7.66	10.72	13.79	15.32	16.85	19.92	22.94	
Western.....	1.90	2.65	3.41	3.79	4.17	4.93	5.68	3.23	4.62	5.81	6.46	7.11	8.40	9.69	2.32	3.25	4.18	4.64	5.10	6.03	6.96	5.13	7.18	9.23	10.26	11.29	13.34	15.39	
Minnesota:																													
Eastern.....	3.18	4.44	5.72	6.35	6.98	8.26	9.52	3.23	7.32	9.31	10.46	11.51	13.60	15.69	2.91	4.07	5.24	5.82	6.40	7.57	8.73	8.40	11.76	15.12	16.60	18.48	21.44	24.50	
Iowa.....	4.26	5.97	7.68	8.33	9.08	10.99	12.80	5.74	8.03	10.32	11.47	12.62	14.61	17.20	3.86	5.40	6.94	7.71	8.48	10.02	11.56	10.00	14.00	18.00	20.00	22.00	26.00	30.00	
Missouri.....	5.94	8.32	10.69	11.88	13.03	15.44	17.82	6.04	8.46	10.88	12.09	13.30	15.72	18.14	4.86	6.80	8.75	9.72	10.69	12.64	14.58	11.98	16.00	17.81	21.57	23.97	26.37	31.65	
Arkansas.....	7.26	10.17	13.08	14.15	15.18	18.89	21.80	5.67	7.94	10.21	11.34	12.47	14.74	17.01	5.16	7.22	9.29	10.32	11.35	13.42	15.48	12.94	18.41	21.28	23.86	28.46	33.08	38.80	
Louisiana.....	6.96	9.74	12.53	13.92	15.31	18.10	20.88	5.94	11.11	14.28	15.87	17.46	20.33	23.80	5.46	7.61	9.78	10.87	11.96	14.13	16.30	14.90	20.85	25.81	29.79	32.77	38.78	44.80	

The autumn precipitation histograms have some peculiar aspects. Those for the western and the eastern groups represent almost normal distributions with the same approximate mode in each case, 96 percent. However, wide variations between them are indicated, the eastern showing a larger number at the central group. For the central Plains there is shown an interesting bimodal distribution. It is far from normal, but the reason is obscure.

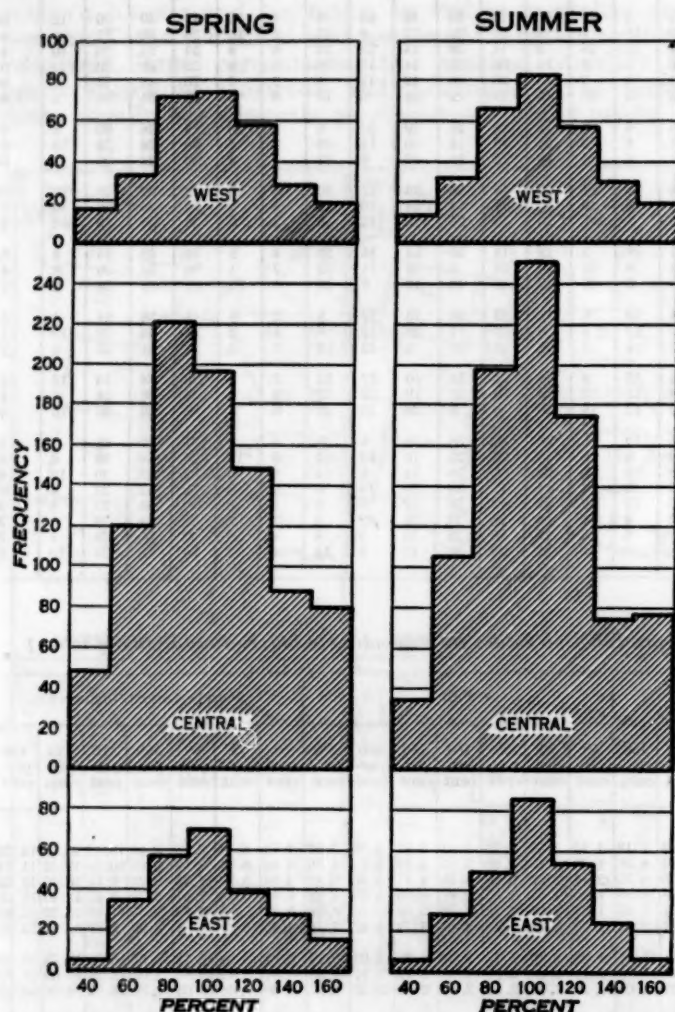


FIGURE 5.—Histograms of precipitation. Upper figure for Western Great Plains: Montana, Wyoming, Colorado, and New Mexico. Central figure for Central Great Plains: North and South Dakota, Nebraska, Kansas, Oklahoma, and Texas. Lower figure for Eastern Great Plains: Minnesota, Iowa, Missouri, Arkansas, and Louisiana.

The histograms for the March-August precipitation represent a closer approach to a normal distribution than is shown for the shorter period. In all cases the mode is only 1 or 2 percent removed from the mean, indicating a distribution very near normal. While the western and central Plains again show a tendency to skewness, the frequencies in the eastern portion are so nearly normal that no unusual features are apparent.

The average annual precipitation in the Great Plains decreases irregularly from east to west and any study of this area should take this feature into account. Therefore, as the Central States were divided into three sections corresponding to eastern, central, and western subdivisions, these were combined into definite areas as the east-central, central, and west-central Great Plains.

The histogram for the precipitation in these areas is given in figure 7. The east-central diagram is quite markedly skewed with the mode 92 percent, or definitely

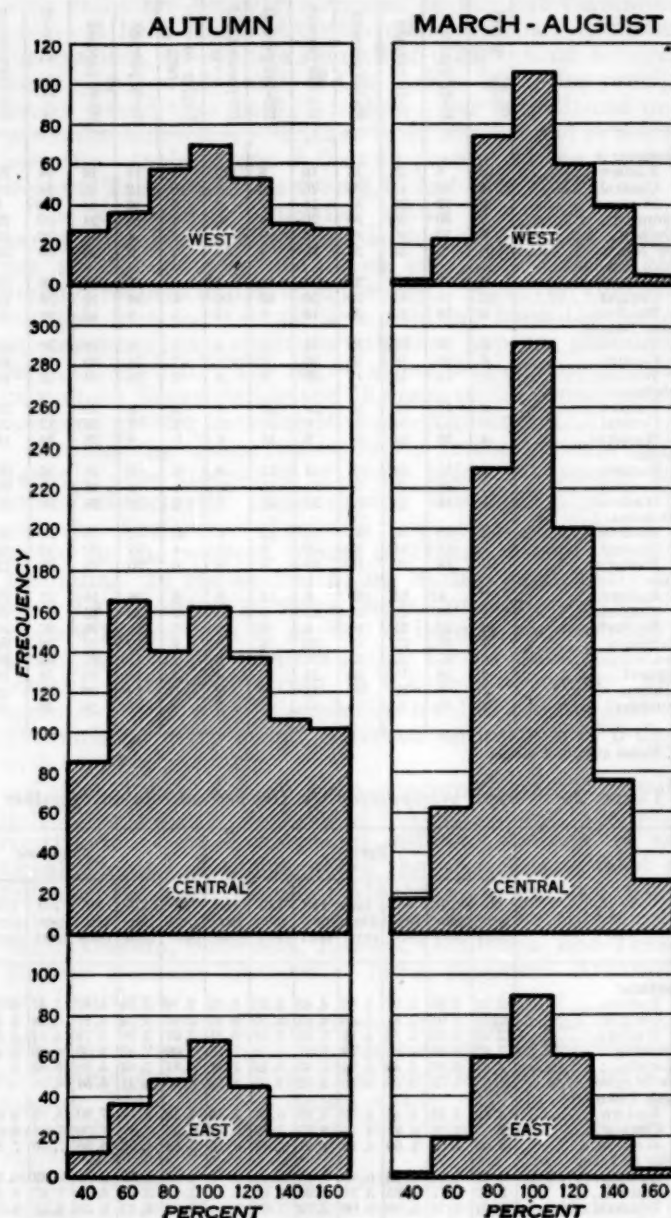


FIGURE 6.—Histograms of precipitation. Upper figure for Western Great Plains: Montana, Wyoming, Colorado, and New Mexico. Central figure for Central Great Plains: North and South Dakota, Nebraska, Kansas, Oklahoma, and Texas. Lower figure for Eastern Great Plains: Minnesota, Iowa, Missouri, Arkansas, and Louisiana.

toward the lesser amounts. A great preponderance of subnormal precipitation frequency is shown in the central diagram, where the approximate mode is 90 percent, while a still greater skew tendency becomes apparent in the west-central area where the most frequent group is dominantly 70-89 percent, with the mode 85 percent or slightly above the median of this group.

Summer precipitation, on the other hand, as shown both in figure 7 and in the general histograms, reverts closely to the so-called "normal" distribution. The preponderance is clearly on the mean groups, with the eastern diagram almost normally distributed. However, the frequencies in the central and western group again tend

toward the lesser amounts, with the modes 95 and 96 percent, respectively. The central diagrams show a tendency toward increased frequencies in the 150+ percent group, probably due to a number of heavy rains.

Autumn precipitation, as before, represents an abnormal condition. Undoubtedly there are some phenomena

In a study of figure 9, it should be borne in mind that each entry represents a 5-year average up to and including the date of entry.

In the trend study no effort was made to group the States into major sections of the Plains as was done for the histograms. The general tendencies are not uniform throughout the area and the individual State trends were believed to be of more dominant importance. The erratic tendencies of autumn precipitation were not believed of sufficient value to include and, consequently, figure 9 contains only the March-August data.

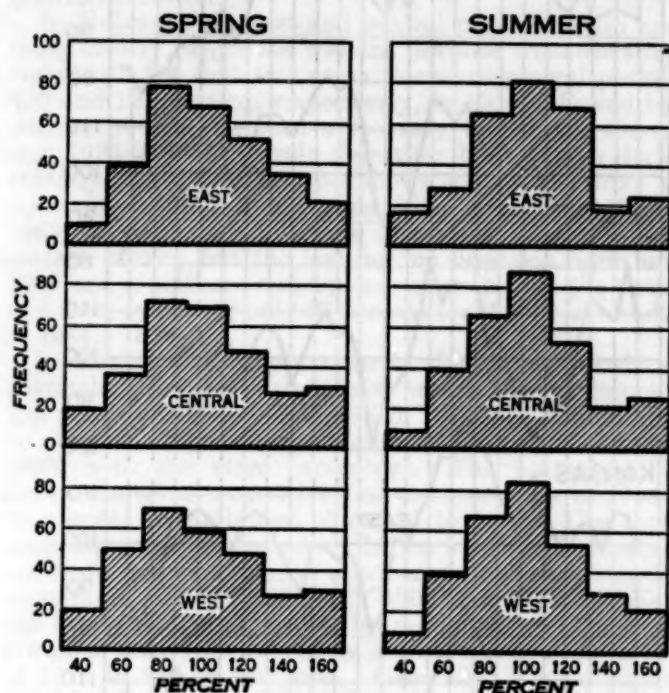


FIGURE 7.—Histograms for Sectional Precipitation. Upper figure for East-Central Great Plains: Eastern divisions of North and South Dakota, Nebraska, Kansas, Oklahoma, and Texas. Central figure for Central Great Plains: Central divisions of North and South Dakota, Nebraska, Kansas, Oklahoma, and Texas.

connected with autumn rains that definitely cause these abnormal distributions. The east-central diagram is probably the nearest approach to a "normal," but even this shows a rapid increase in the lower frequencies that effectively counteracts any weight the higher ones might give. The absence of a pronounced central tendency, such as a normal distribution would require, is also striking. In this distribution the approximate mode is 90.

The diagram for the central Great Plains, just as abnormal as the general one, again is characterized by light precipitation, shown by the dominant frequency of 50-69 percent. The mode in a distribution of this type is almost impossible to determine with any great degree of accuracy, hence it was not computed. The western Great Plains, however, represent the most abnormal distribution yet encountered. The mode approximately falls both in the 50-69 percent and 90-109 percent frequencies.

The March-August precipitation, as before, shows a general tendency to an ideal normal distribution. The mode for the east-central diagram is practically the same as the mean, while that for the central diagram is only 1 percent below the mean. The west-central group is again markedly abnormal, with the frequencies grouped heavily around the midpoint, the three central groups being within 17 of each other. The mode in the latter diagram is only 98, indicating the great preponderance of the central groups.

The general trend of precipitation is an important matter in these areas, and it is of considerable interest that figure 9 shows quite similar trend tendencies in many sections.

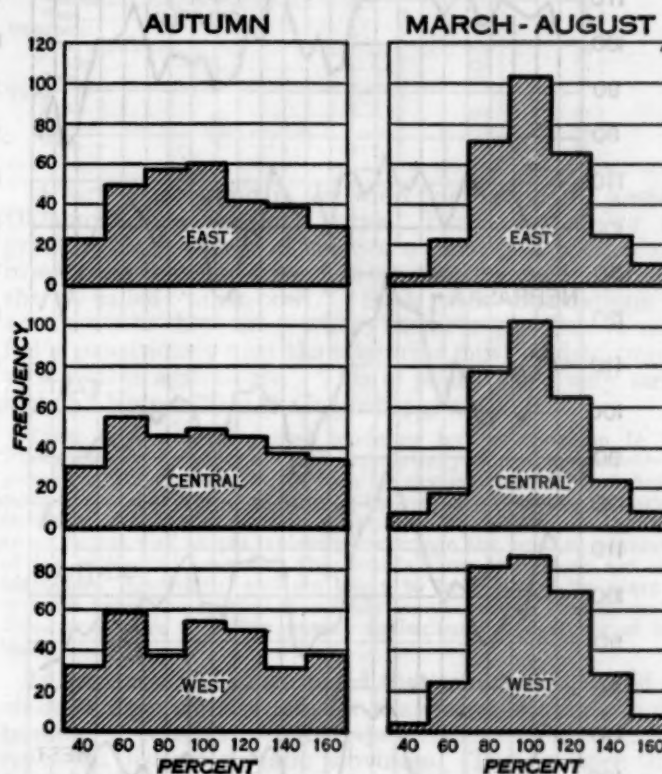


FIGURE 8.—Histograms for Sectional Precipitation. Upper figure for East-Central Great Plains: Eastern divisions of North and South Dakota, Nebraska, Kansas, Oklahoma, and Texas. Central figure for Central Great Plains: Central divisions of North and South Dakota, Nebraska, Kansas, Oklahoma, and Texas.

A 5-year moving average of percent of normal precipitation for North Dakota for the period March-August, inclusive, is shown in the figure. It shows for the different sections of the State quite similar trends. The period 1894-1909 was one of generally adequate precipitation in all parts of the State, although the excesses were not so marked in the central and western areas and declined to subnormal in the western section by 1901. The general decline in western North Dakota may be said to have begun in 1905 as none of the subsequent years approaches the peak of that year. There was some recovery from 1910 to 1916 and again from 1921 to 1928, but from the latter year through 1936 the period was one of generally deficient precipitation. Similar conditions prevail in the central and western sections and, although there was a brief tendency toward recovery in 1936, the general trend is still to below normal.

In South Dakota marked variations are indicated between the east, central, and western sections. The first two show quite similar tendencies, with increasing precipitation from 1891 to 1909, a marked decline through 1913, rapid recovery to 1917 or 1918, and a gradual and persistent decline from then through 1936. In the east a

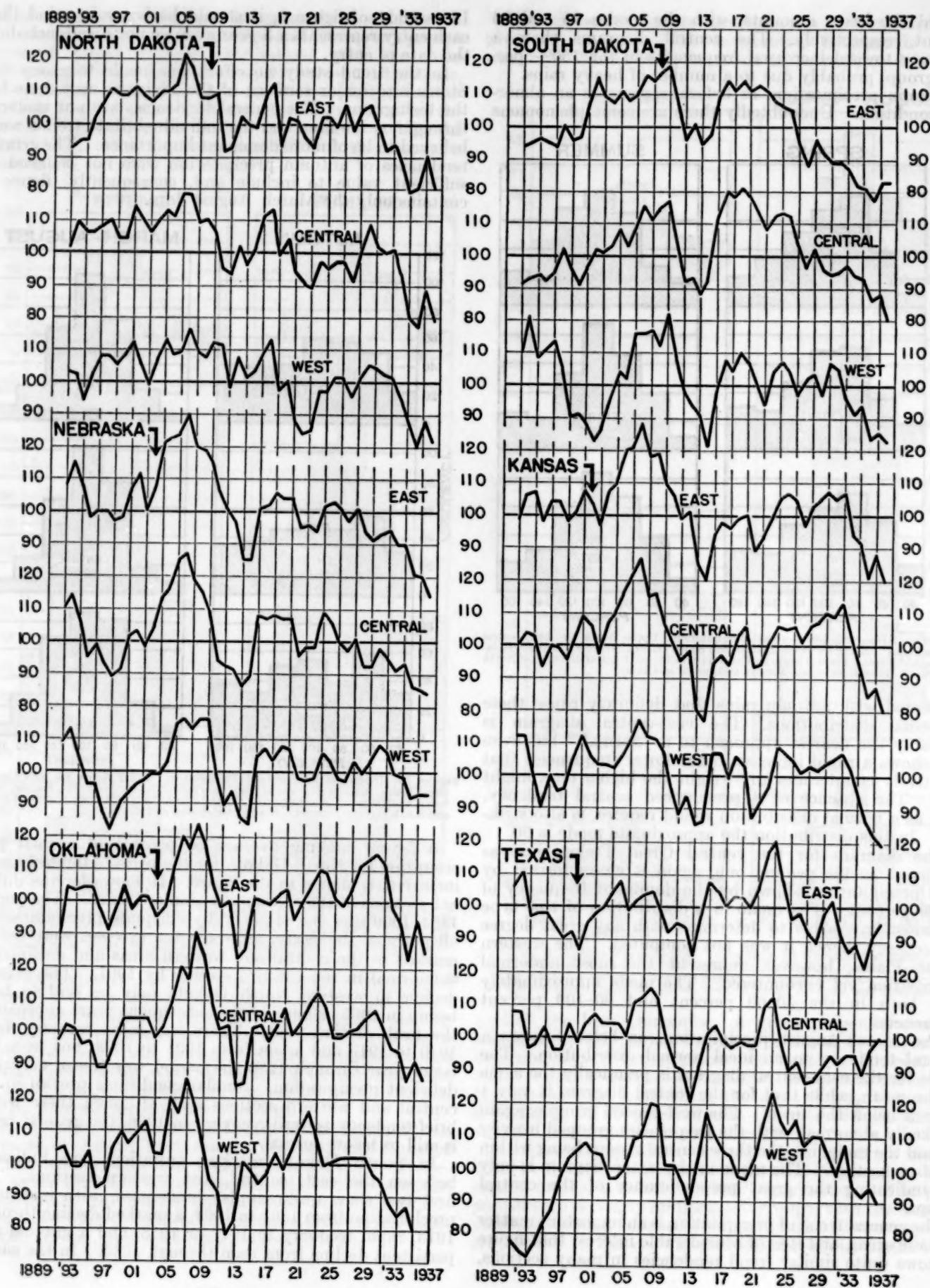


FIGURE 9.—Five-year moving averages of percent of normal precipitation for March-August.

break in the downward trend appears in 1935 and 1936, but is too indefinite for significant appraisal. The west shows a decline from a 5-year average of 120 percent in 1892 to 83 percent in 1900, a sharp recovery to the maximum of 122 in 1909, another decline to the minimum of 81 in 1914, partial recovery to 110 in 1918, and a general decline thereafter.

In Nebraska the east and central portions again agree fairly closely, while the western deviates somewhat from these. In the first two areas there are general peaks of 130 and 127 percent, respectively, in 1906, followed by a decline to 1913-14, then a recovery to 1917 in the east and 1923 in the central; thereafter both curves decline steadily to 1936. The west shows a rapid rise from the minimum in 1897 to a general high level from 1905 to 1909, the depression following agrees with the central and eastern curves, but the last decline does not begin until 1930 and is neither as abrupt nor as deep as in the central and east, averaging only 93 percent for the 5 years ending in 1936.

In Kansas wide fluctuations in the curves are shown, particularly in the eastern part where the maximum of 128 percent in 1906 is followed in 1914 by a minimum of 80 percent. The other minimum of the period occurs in 1936, with the same percentage. The central section shows the same tendencies, but the minimum in 1914 of 77 percent is the lowest of record to 1936. The actual recession is less in the west. In the west the fluctuations are more frequent than in other areas, but are of smaller amplitude. The maximum of 1906 is not as high as in the other cases and, while the minimum of 1936 is the lowest of record for this division, it is not as deep as that of 1914 in the central area. Generally, Kansas rainfall for this March-August period shows no long-time stabilization.

In Oklahoma the depression in 1934-36 has been equaled or exceeded in 1913 in all divisions. The maximum in 1907-08 is somewhat later than in the other States. The secondary maximum of 1930 in the eastern district is not as pronounced in the central and is lacking in the west. The precipitation in the west declined steadily from 1922 to 1936, although there was a period from 1925 to 1929 with slightly above normal precipitation.

In Texas there is a marked variance between the sections for the period 1891-1900. In the east the curve begins substantially above normal and declines to 1899, while in the central it fluctuates above and below normal for this period. In the west, however, the period begins much below normal, declines slightly to 1893, then recovers with a continuous advance to 1900. Throughout the remainder of the curve there is agreement rather closely with other areas until 1923, with maxima in all divisions. The central and eastern curves then decline to 1927 and 1934, respectively. Thereafter, the central section continues somewhat below normal for a number of years, but reaches normal again in 1936. The eastern graph makes a brief recurve above normal in 1936. In the west, however, there is a progressive decline in precipitation from 1925 to 1936, broken by occasional recoveries, but maintaining a continuous downward trend, ending 10 percent below normal in 1936.

It is interesting to observe in this series of curves that the eastern, or subhumid section of the Plains shows as wide variations as the western. For example, in North Dakota the range is from 121 percent to 79 percent in the east, an amplitude of 42 percent; in the central 118 to 78 percent, or of 40 percent; and in the west 116 to 80, or only 36 percent.

In the other States the maxima and minima percentages and ranges are as follows:

	Maximum	Minimum	Range
	Percent	Percent	Percent
South Dakota:			
East.....	119	77	42
Central.....	121	80	41
West.....	122	81	41
Nebraska:			
East.....	130	74	56
Central.....	127	84	43
West.....	116	82	34
Kansas:			
East.....	128	80	48
Central.....	126	77	49
West.....	117	79	38
Oklahoma:			
East.....	124	82	42
Central.....	130	83	47
West.....	126	78	48
Texas:			
East.....	121	81	40
Central.....	115	80	35
West.....	124	73	51

A significant trend is the wide fluctuations in western Oklahoma and western Texas. The latter shows the greatest range of any of the States, and it is particularly interesting that portions of these districts are included in the so-called "dust-bowl." Such wide fluctuations as are shown in these areas where the average effective rainfall is precariously near the minimum must be detrimental to a settled agriculture. This is pointed out very strikingly by Kincer (9) in the following quotation:

There is a well-recognized tendency for precipitation in the Plains Region to show several successive years of comparatively generous rainfall, followed in turn by several years with deficient moisture, and this renders farming by ordinary methods precarious in many of the drier western portions of the section. Abundant crops in years of ample moisture encourage the western extension of the cultivated area, but the records show that these are only temporary conditions, and are likely to be followed by years of drought when the rainfall is entirely insufficient to mature crops. Disaster is sure to follow unwise agricultural adventures of this kind.

It was previously mentioned that an attempt would be made to examine the data for the various sections to determine, if possible, whether the divisions as herein used represent distinct climatic provinces. The evidence thus far submitted indicates to some extent that the sections are generally in fair agreement, at least as regards frequencies of different amounts of precipitation.

However, a striking phase is the variation in the 5-year moving average curves between States. For example, those for eastern North and South Dakota show marked divergencies between 1893 and 1899, and again between 1916 and 1928. The central portions of these States also show similar disagreements, especially between 1916 and 1925. In the west the curves are out of phase until 1905, but agree roughly from then to 1936, except for the years 1912-14. There seems to be a slight tendency toward agreement between central North Dakota data and western South Dakota data. The eastern and central sections of the respective States also seem to be in slight agreement.

The several sections of South Dakota and Nebraska are in quite close agreement, except for a deflection of the minima in western Nebraska to the left of that for South Dakota, or approximately 3 years earlier.

The comparison between Nebraska and Kansas shows a very close agreement generally. In the eastern portions there is a tendency for Kansas to have higher values from 1927-31, as well as from 1926-1932 in central districts. The western sections show quite close agreement, the only marked discrepancy being in the years 1898-1901 when Kansas recorded somewhat higher values.

Kansas and Oklahoma data also agree very well, except in the deflection of the Oklahoma maxima to the right, or two years later than Kansas, in all sections. The western portions of these States show more deviations between the curves than the central and eastern districts. Reversals of trend for these curves are indicated in 1902, 1907, 1912, 1915, 1916, 1920, and 1930-31.

Oklahoma and Texas, however, again indicate a tendency similar to those for the Dakotas. Eastern Oklahoma agrees fairly well with central Texas especially during early years. A reversal of trend occurs during the years 1927-31, when eastern Oklahoma data show a tendency to above normal values and Texas the reverse. Agreement is quite close between central Oklahoma and western Texas, the only serious difference occurring in early years, between 1891-1896, which probably may be due to nonhomogenous data. The western portions of these States, however, are in fair agreement, also indicating that the central and western Oklahoma data are more nearly comparable with western Texas.

As general conclusions on the matter of section similarity, the divisions in the central portion of the Plains seem to be well chosen, but adjustments are indicated in both the northern and southern extremes. As considerable labor would be involved in these redistributions, and the adjustments of only minor climatic importance, it scarcely seems advisable under present circumstances.

Considering the Great Plains, as a whole, there is remarkable uniformity in its precipitation distribution. The general tendency to a moderately skewed distribution is of course, to be expected, but the marked bimodal distribution of autumn precipitation awaits some logical explanation. Indications point toward a great frequency of very light precipitation as the cause. This frequency of precipitation in the 50-69 percent groups indicates an average daily rainfall of only 0.13 inch, based on an average precipitation for the area of 1.94 inches and 5 days of rain per month.

Several clues as to the lack of substantial precipitation are offered by Holzman (10). The theory that air masses

may remove moisture from the land and only reprecipitate it under favorable conditions, and then only in insignificant amounts, may contribute largely to the lack of appreciable precipitation in the Great Plains in autumn. At this season the general movement of air masses ordinarily becomes somewhat accelerated and the Great Plains becomes invaded more frequently by the large Pc masses and thus conditions become more unfavorable for appreciable precipitation. Also, the more definite movement of the Pm and Pr air contribute more toward the "Chinook" effect, thus again reducing the chances for significant precipitation. It also appears that definite invasion of the region by an active air mass, probably from the Southwest or Northwest is necessary to substantial rainfall, and only in this event would the daily amounts be of sufficient magnitude to increase the seasonal totals to an entirely different class frequency.

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A STUDY OF THE HOURLY PRECIPITATION AT OKLAHOMA CITY, OKLA.

By H. F. ALEXANDER

[Weather Bureau Airport Station, Wynoka, Okla., October 1937]

Numerous studies of the hourly distribution of precipitation have been made during the past quarter of a century, but since all such studies are more or less local in character, it has been deemed worth while to make a similar investigation of the Oklahoma City data. Material of this kind is of value in determining rainfall insurance rates, in making local weather forecasts, in planning outdoor activities, and as a contribution to climatology.

The records for the years 1911 to 1935, inclusive, embracing a period of 25 years, were used. The data for each month, consisting of the hourly amounts and the beginning and ending of each period of precipitation, were entered on a suitable form, after which the totals and averages were obtained. All averages used in this study are for the entire 25-year periods; in cases where there was a break in the record of hourly precipitation, as often occurred during the winter months when there was no automatic record, it was deemed permissible to interpolate the hourly amounts.

A bibliography of easily accessible papers on similar investigations is appended.

AVERAGE HOURLY AMOUNTS OF PRECIPITATION

The average hourly amounts of precipitation for each of the 24 hours are given in Table 1 for the months and for the year. The average hourly amounts for the daytime (7 a. m. to 7 p. m.) and nighttime (7 p. m. to 7 a. m.) periods are given in the table also.

The data reveal the existence of a distinct diurnal period in the average hourly amounts of precipitation occurring at Oklahoma City, especially during the spring, summer, and autumn months. This characteristic begins to be apparent in March and continues throughout the summer season and into November. With the exceptions of May and July, there is a well-defined maximum period beginning just after midnight and extending until about 7 a. m.; the greatest average hourly amounts for April, June, August, and September occur between 1 a. m. and 3 a. m. There is also a well-defined secondary maximum in the late afternoon and early evening hours during the summer months.

The greatest average precipitation for any hour of the year is 0.35 inch between 1 a. m. and 2 a. m., in June; the least, 0.02 inch between 3 p. m. and 4 p. m., is also in June.

It is interesting to compare the average hourly amounts that occur during the daytime with those occurring during the nighttime for a station such as Oklahoma City which may be considered to typify the conditions prevailing over a considerable area in the Great Plains region. There are no marked differences between the average amounts of daytime and nighttime precipitation at Oklahoma City during the winter season; they are practically the same for the months of November, December, and January; February, however, shows a slightly greater average for the nighttime. During the warm summer months (June, July, and August) from one and one-half to two times as much precipitation occurs during the nighttime than during the daytime. In the spring and autumn months the average amounts are almost exactly divided between daytime and nighttime. Of the 12 months, October, alone, shows a greater average hourly precipitation for the daytime.

As pointed out by Kincer¹ it is a fortunate provision of nature that an excess of the total precipitation of the central Great Plains region occurs during the nighttime when it may be more economically utilized by growing plants. It is well known that evaporation takes place much more rapidly during the daytime when excessive heat and high winds dry the soil very rapidly and vitiate any benefit that might accrue from light showers. Light showers in the daytime followed immediately by very high temperatures may even be distinctly harmful to tender vegetation. On the other hand, nighttime precipitation may be more economically utilized by growing plants, and the benefits are of a more lasting nature. The trend of the distribution of rainfall to the nighttime hours is doubtless of considerable value to farmers in this region, since a light seasonal precipitation, if properly distributed, may be sufficient to produce a fair crop.

There is no doubt that the diurnal variation in the amounts of precipitation is ultimately connected with the distribution of thunderstorms, which, in turn, is associated with changes in temperature and pressure. The distribution of thunderstorms is the controlling factor in determining the daily variations in precipitation during the warm months in middle latitudes. The more or less even distribution of precipitation throughout the day and night during the winter months is characteristic of a wide area in the central portion of the United States, and is due to the small number of thunderstorms experienced during that season. Most precipitation in this area during the winter months is the result of general cyclonic storms and, consequently, exhibits no distinct diurnal period.

THE DURATION OF PRECIPITATION

Comparatively little research has been done on the problem of the duration of precipitation in the United States. Therefore, it was deemed worth while to compile such data for Oklahoma City for the period 1911-35, inclusive. Note was made of the time of beginning and ending of each period of precipitation and all intervals between showers were eliminated from the computations. In cases where the exact time of beginnings and endings was not known the times were approximated; most cases of this kind occurred at night, and were more frequent

prior to 1928, when the inception of the airway service at Oklahoma City made it possible to check more closely the beginnings and endings of showers.

In the study of the duration of precipitation it seems desirable to disregard the intensity, and to consider hours with traces along with those having measurable amounts. Whenever the duration is computed with reference to selected hourly amounts of light intensity, serious error may result, since many hours credited with measurable amounts will simply represent the cumulative totals of previous hours.

The average annual duration of precipitation in Oklahoma City for the period 1911-35, inclusive, is 562.8 hours, or 6 percent of the total possible time. Of the total, 276.3 hours occur during the daytime (7 a. m. to 7 p. m.), and 286.5, or slightly more than half, occur at night.

The period of greatest monthly total duration begins with the late autumn months, extends through the winter, and ends in May. January and December, with averages of 67.5 and 66.2 hours, respectively, have considerably greater total duration than any other months of the year. It is also very noticeable that the daytime and nighttime durations for the period beginning with October and ending with May are almost equal, but slightly greater for the daytime in all except March and May.

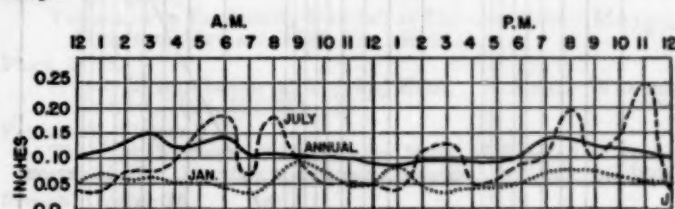


FIGURE 1.—Average hourly amounts of precipitation at Oklahoma City, Okla., 1911-35 inclusive.

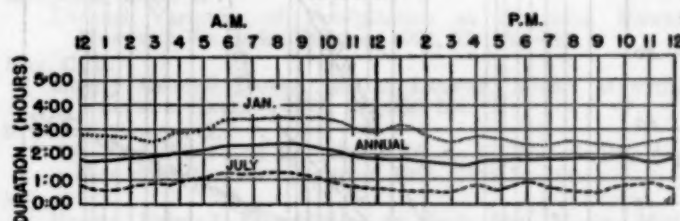


FIGURE 2.—Average hourly duration of precipitation at Oklahoma City, Okla., 1911-35 inclusive.

The duration of precipitation is much shorter during the summer months; it is about one-half or one-third as great as in the months of greatest duration. July, with an average of 19.9 hours, has the least total duration of any month. It should be noted that the nighttime is greater than the daytime duration during the months of May to September, inclusive. This difference is greatest in June, when, on an average, 59 percent of the rainfall hours occurs between 7 p. m. and 7 a. m.

Comparisons between the various months of the duration of precipitation may be more accurately made when percentages of the total possible time are used, thus eliminating discrepancies due to the unequal lengths of the months. These percentages for Oklahoma City are as follows: January, 9; February, 8; March, 8; April, 7; May, 6; June, 4; July, 3; August, 4; September, 5; October, 6; November, 8; and December, 9. Taking the year as a whole, precipitation in some form is falling 6 percent of the time.

¹ J. B. Kincer, Daytime and Nighttime Precipitation and Their Economic Significance. MONTHLY WEATHER REVIEW, 44: 630, 1916.

The average duration for each hour of each month is given in table 2. Data for selected months, as well as the annual averages, are given in graphic form in figure 2. The maximum average duration, for the year as a whole, occurs in the hour ending at 8 a. m., while the minimum occurs between 2 p. m. and 3 p. m. There is a gradual increase in the average duration from midnight to 8 a. m.; thereafter a more rapid change takes place with the duration decreasing until 3 p. m. Probably the most outstanding feature exhibited by the data in table 2 is the persistency of the maximum in occurring between the hours of 5 a. m. and 10 a. m. throughout the year. In this respect the seasonal variations differ little from the annual. While there are no secondary maxima or minima of importance, there is a slight tendency for an increase in the average duration during the hours between sunset and about 11 p. m. from April to August, inclusive.

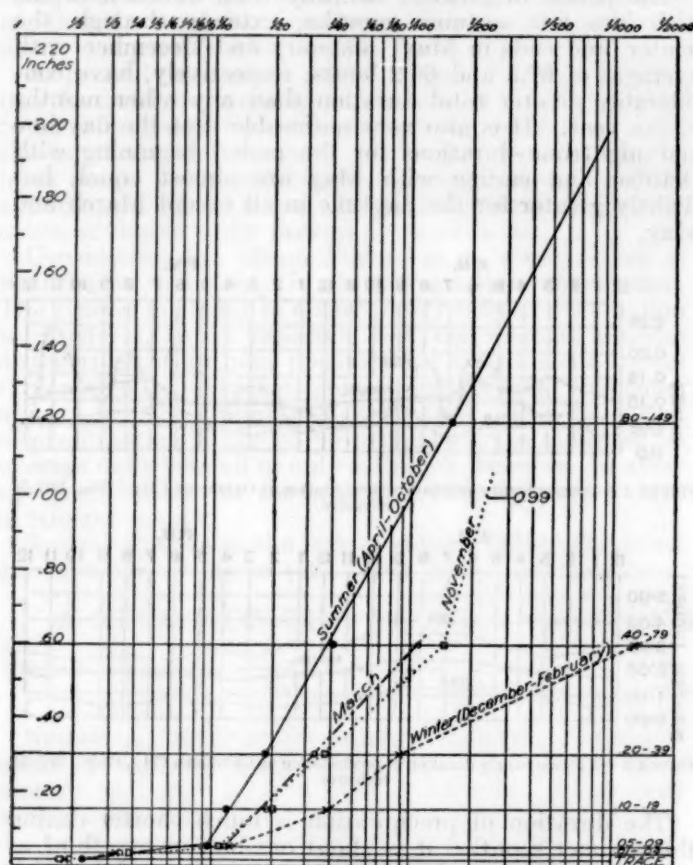


FIGURE 3.—Frequencies of intensity groups relative to total hours with precipitation at Oklahoma City, Okla., 1911-35, inclusive. Graphical representation of data presented in table 5.

The greatest hourly duration in any month occurs in January between 8 a. m. and 9 a. m., when it averages 3 hours and 26 minutes. Several other hours between 5 a. m. and 10 a. m. in January also have a large average duration. The least duration in any month occurs in July between midnight and 1 a. m. when it averages only 30 minutes.

FREQUENCY AND INTENSITY OF PRECIPITATION

In studying the frequency of precipitation it is desirable to recognize the existence of several inherent characteristics of the data under consideration. Most important of these is the fact that the hourly entries of precipitation really represent random samples, since the 24 hours of the day are arbitrarily taken as the limits of the hourly

periods. The irregular distribution of precipitation throughout the day and night results in much overlapping from one hour into the next; thus, a shower of only a few minutes duration may extend from the latter part of one into the early part of the following hour, and result in 2 hours record of precipitation. Also, a compilation of this kind involves such a large mass of data, with so many subdivisions, that special graphical methods are necessary to present the facts properly.

Table 3 shows the frequency of occurrence of hours with a trace or more, expressed as a percentage of the number of times that the particular hour occurs in the month. As would be expected, the greatest hourly frequency occurs during the period November to March, inclusive, when precipitation is recorded during about 10 percent of both the daytime and nighttime hours. The frequency distribution is fairly uniform throughout the 24-hours during the colder months of the year, but, in general, there seems to be a slightly greater frequency during the daytime.

The maximum hourly frequency occurs in the early morning hours in all months of the year; generally between 5 a. m. and 10 a. m. from September to April, inclusive, and from 6 a. m. to 8 a. m. from May to August, inclusive.

July, with an average frequency of 4 percent of the possible hours with rain, has the least frequency of any month in the year. The hour between midnight and 1 a. m., when 2 percent of the total hours have rain, has the least frequency of any hour during the year.

The following discussion of rainfall frequencies and intensities is based to a great extent upon the plan used by McDonald.² It was thought desirable to use the same intensity groups and the same graphical methods for Oklahoma City, in order that the precipitation data for the two cities might be compared.

In order to provide a means of comparison between the various intensity frequencies, the hourly totals were arranged into a table of frequencies under the following headings: Trace; 0.01 to 0.04; 0.05 to 0.09; 0.10 to 0.19; 0.20 to 0.39; 0.40 to 0.79; 0.80 to 1.49; and 1.50 inches and over. It will be noticed that the groups increase in approximate geometric ratio.

In table 4 all hours with precipitation during the period 1911 to 1935, inclusive, have been referred to their respective intensity groups. In the first column are given the total hours with precipitation during the 25-year period together with the partial totals for daytime and nighttime. Reference to this table shows that hours with only a trace are greater during the daytime (7 a. m. to 7 p. m.) in all months of the year, the excess over the nighttime hours being greatest during the period December to April, inclusive. On the other hand, there seems to be a well-defined tendency for the greater rainfall intensities to occur more frequently during the nighttime during April, June, July, August, and September. During other months, however, the distribution of hours with measurable rainfall seems to be largely fortuitous.

Table 5 is based upon table 4, and shows the relative frequency of the various groups as compared with the total rainy hours in each month. The smaller values represent the higher frequencies, since each figure indicates the average number of samples that would be necessary, as a rule, to obtain one example of the desired intensity. In other words, during the month of February, 1 hour in 3 with precipitation has had an intensity varying from 0.01 to 0.04 inch.

Although there is a wide range in the total number of hours with precipitation in the lower intensity groups,

² W. F. McDonald, Hourly Frequency and Intensity of Rainfall at New Orleans, La. MONTHLY WEATHER REVIEW 57:1-8, Jan. 1929.

table 5 indicates that the chance of a rainfall occurring with an intensity of 0.04 inch or less per hour is approximately the same in all months. Considerable divergence in this respect is manifest in the 0.05 to 0.09 inch group, and this tendency persists throughout the year in all the higher intensity groups.

In order to present graphically the data contained in table 5 it was thought desirable to construct figure 3, which represents the frequency distribution of the various intensity groups. Ordinary curves are inadequate to show the relationships existing among large groups of data of this nature, so it was found necessary to plot the data on ratio-ruled paper. Any grouping of data into a straight-line relationship by this method is, as a rule, evidence of an underlying causative factor affecting the entire series. The data for the various months were arranged into groups representing the winter and summer seasons, while the intermediate months were considered separately. The winter season embraces the months of December to February, inclusive, the summer season, April to October, inclusive, while March and November, being transitional in character, were treated separately.

It is notable that the lines on the graph representing the three lowest intensity groups practically coincide for all seasons of the year. Beginning with the 0.05 to 0.09 inch group, however, there is a wide divergence in the lines representing the seasons.

The data for the summer season, especially, group themselves into a straight-line relationship, which is indicative of a single underlying causative factor (convection). The lowest intensity group totals, which, of course, have the greatest frequencies, form the first division of the graph; that is, they include those rainy hours during the summer season which are due to a combination of several causes. Starting with the fourth group, however, there is a continuous straight-line relationship that may be explained only by the fact that practically all summer-time rains of these higher intensities are due to thunderstorm activity.

The frequency distribution of various hourly amounts for the winter season does not show the close internal relationship manifested by the summer season. The hourly intensities are much lighter than during the summer, since thunderstorm activity is at a minimum. During the months of December to February, inclusive, there is a more pronounced tendency for the straight-line relationship to persist through the 0.10 to 0.19 inch group than in the summer season. This tendency is due to the fact that converging winds and the elevation of masses of air are responsible for a greater percentage of the hours with precipitation during the winter season, and, further, that these causal factors produce greater hourly intensities during the cooler portion of the year.

The months of March and November, being transitional in character, have been treated separately on the graph. Several causative factors are at work producing the precipitation that occurs during these months. It will be noted that the data for March assume a well-defined straight-line relationship, but it is thought that this result is more or less fortuitous, since convection, convergence, contact cooling, etc., are all active at that time of the year in Oklahoma City and produce a more or less haphazard precipitation pattern.

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TABLE 1.—Average hourly amounts of precipitation at Oklahoma City, Okla., 1911-35, inclusive

	A. M.												P. M.												Hourly averages		
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	Day-time	Night-time	Month
January.....	0.07	0.06	0.06	0.05	0.05	0.04	0.03	0.06	0.09	0.07	0.05	0.05	0.08	0.04	0.03	0.04	0.04	0.05	0.07	0.07	0.07	0.06	0.05	0.05	0.06	0.06	0.06
February.....	0.05	0.04	0.04	0.05	0.04	0.04	0.06	0.05	0.03	0.05	0.06	0.05	0.04	0.04	0.03	0.04	0.03	0.05	0.06	0.05	0.04	0.06	0.05	0.04	0.06	0.05	0.05
March.....	0.10	0.10	0.17	0.10	0.14	0.15	0.08	0.07	0.11	0.08	0.09	0.07	0.06	0.04	0.07	0.07	0.09	0.07	0.11	0.14	0.06	0.13	0.08	0.11	0.09	0.11	0.09
April.....	0.16	0.15	0.24	0.22	0.20	0.18	0.12	0.10	0.16	0.10	0.14	0.10	0.07	0.10	0.10	0.22	0.19	0.07	0.09	0.11	0.16	0.12	0.10	0.07	0.12	0.15	0.14
May.....	0.08	0.13	0.16	0.15	0.14	0.17	0.19	0.21	0.19	0.22	0.21	0.17	0.12	0.14	0.18	0.14	0.13	0.12	0.24	0.28	0.21	0.18	0.22	0.18	0.17	0.17	0.17
June.....	0.20	0.35	0.32	0.17	0.21	0.28	0.09	0.11	0.14	0.08	0.09	0.06	0.08	0.17	0.06	0.02	0.07	0.12	0.12	0.23	0.26	0.15	0.17	0.09	0.21	0.15	0.15
July.....	0.03	0.07	0.07	0.09	0.16	0.18	0.07	0.18	0.09	0.05	0.05	0.05	0.03	0.11	0.13	0.05	0.05	0.08	0.10	0.19	0.10	0.14	0.25	0.03	0.08	0.12	0.10
August.....	0.20	0.12	0.27	0.22	0.17	0.21	0.15	0.10	0.07	0.07	0.08	0.07	0.09	0.10	0.07	0.12	0.08	0.10	0.14	0.10	0.07	0.05	0.05	0.09	0.09	0.14	0.12
September.....	0.14	0.26	0.12	0.14	0.21	0.14	0.20	0.14	0.12	0.08	0.10	0.08	0.05	0.08	0.13	0.09	0.08	0.19	0.25	0.14	0.14	0.12	0.13	0.12	0.16	0.14	0.14
October.....	0.11	0.14	0.15	0.12	0.14	0.16	0.18	0.15	0.09	0.16	0.24	0.17	0.21	0.17	0.12	0.12	0.11	0.10	0.15	0.15	0.12	0.16	0.07	0.15	0.14	0.14	0.14
November.....	0.10	0.10	0.13	0.05	0.05	0.08	0.07	0.08	0.08	0.13	0.07	0.07	0.11	0.06	0.06	0.08	0.09	0.16	0.13	0.14	0.09	0.09	0.06	0.12	0.09	0.09	0.09
December.....	0.06	0.07	0.05	0.07	0.07	0.07	0.06	0.07	0.08	0.06	0.05	0.06	0.07	0.08	0.07	0.07	0.09	0.12	0.07	0.06	0.11	0.08	0.07	0.07	0.07	0.07	0.07
Means.....	0.13	0.15	0.12	0.13	0.14	0.11	0.11	0.11	0.10	0.10	0.10	0.08	0.08	0.09	0.09	0.09	0.09	0.10	0.13	0.13	0.12	0.11	0.10	0.10	0.12	0.11	0.11

NOTE.—Amounts given are for the 1-hour intervals ending at the designated clock hours. Hourly averages for the daytime and nighttime and the month are given in the columns at the right.

TABLE 2.—Average hourly duration of precipitation at Oklahoma City, Okla., 1911-35, inclusive (in hours and minutes)

	A. M.												P. M.												Totals		
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	Night-time	Day-time	Month
January.....	2:44	2:37	2:29	2:53	3:01	3:20	3:19	3:22	3:26	3:23	3:04	2:55	3:07	2:51	2:29	2:40	2:57	2:23	2:26	2:31	2:24	2:19	2:30	2:40	32:47	34:43	67:30
February.....	1:47	2:01	1:55	2:05	2:21	2:46	2:59	3:06	3:02	3:00	3:02	2:36	2:22	2:10	2:07	2:03	2:04	2:02	2:18	2:31	2:23	2:18	2:14	2:01	27:21	29:52	57:13
March.....	2:25	2:22	2:21	2:20	2:20	2:33	2:24	2:36	2:47	2:39	2:22	2:20	2:11	2:06	2:10	2:33	2:25	2:24	2:28	2:37	2:29	2:32	2:32	2:01	29:11	29:01	58:12
April.....	1:60	1:48	1:59	2:18	2:19	2:22	2:13	2:22	2:22	2:14	2:04	1:56	2:08	2:09	1:56	1:52	1:43	1:46	1:39	1:41	1:49	1:48	1:34	1:34	23:15	24:11	47:26
May.....	1:28	1:52	2:05	2:11	2:11	2:03	2:20	2:32	2:21	2:14	1:53	1:39	1:35	1:23	1:22	1:34	1:42	1:32	1:39	1:44	1:59	2:00	1:56	1:49	23:38	21:26	45:04
June.....	1:38	1:34	2:03	1:52	2:01	1:40	1:48	1:48	1:52	1:31	1:07	0:50	0:55	0:52	0:46	0:44	0:47	0:53	0:59	1:05	1:07	1:23	1:25	1:30	19:06	13:04	32:10
July.....	0:30	0:45	0:53	0:57	1:08	1:11	1:12	1:14	1:06	0:56	0:47	0:41	0:35	0:39	0:37	0:49	0:39	0:54	0:44	0:38	0:37	0:46	0:55	0:39	10:11	9:41	19:52
August.....	1:02	1:11	1:06	1:23	1:34	1:50	1:58	1:41	1:21	1:13	1:01	0:54	0:52	0:48	0:40	0:32	0:48	0:58	1:07	0:56	0:48	1:02	1:03	0:55	14:48	11:55	26:43
September.....	1:35	2:06	2:17	2:16	2:27	2:12	1:58	2:03	1:45	1:24	1:12	1:12	1:10	1:05	1:22	1:16	1:17	1:12	1:08	1:15	1:11	1:16	1:17	1:29	21:19	16:06	37:25
October.....	1:44	2:01	2:07	2:20	2:25	2:17	2:35	2:46	2:29	2:18	2:17	1:53	1:40	1:51	1:50	1:51	1:52	1:42	1:46	1:53	1:51	1:37	1:36	1:40	24:06	24:21	48:27
November.....	2:19	2:12	2:06	2:01	2:08	2:12	2:21	2:44	2:49	2:31	2:12	2:02	2:14	2:16	2:06	2:11	2:26	2:31	2:36	2:34	2:37	2:34	2:24	2:30	27:58	28:38	56:36
December.....	2:33	2:32	2:20	2:35	2:58	2:57	2:56	2:52	2:56	2:55	2:46	2:36	2:41	2:42	2:33	2:41	2:59	2:55	2:42	2:45	2:40	2:57	2:56	2:44	32:53	33:18	66:11
Means.....	1:48	1:55	1:58	2:07	2:15	2:17	2:20	2:25	2:21	2:12	1:59	1:48	1:84	1:44	1:40	1:44	1:47	1:46	1:48	1:51	1:50	1:53	1:51	1:48	23:53	23:02	46:55

NOTE.—Entires represent the average duration per month of precipitation during each hour of the day. Totals for the daytime and nighttime periods, and for the month, are given in the columns at the right.

TABLE 3.—Average hourly frequencies of precipitation, expressed as a percentage of the total possible hours in the month, at Oklahoma City, Okla., 1911-35, inclusive

	A. M.												P. M.												Averages		
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	Day-time	Night-time	Month-ly
January.....	10	9	10	11	12	13	12	13	13	13	11	12	12	12	11	10	10	9	10	10	9	9	9	10	11	10	11
February.....	7	9	8	9	11	11	12	14	13	13	12	12	10	9	9	10	9	8	9	10	10	9	9	8	11	10	10
March.....	9	9	10	9	9	10	10	11	11	11	10	10	10	9	9	10	10	10	10	11	10	9	10	8	10	9	10
April.....	7	8	8	9	11	11	12	10	11	12	10	10	10	9	9	10	9	8	9	8	8	9	8	7	7	10	9
May.....	6	6	7	8	8	9	10	11	13	11	10	9	8	7	7	7	8	9	7	8	9	10	9	8	8	9	9
June.....	6	8	8	9	9	9	10	11	9	8	7	5	6	5	5	5	6	6	6	6	5	7	6	6	7	7	7
July.....	2	3	4	5	5	6	7	7	6	5	4	3	3	4	4	5	4	5	4	3	3	4	4	3	5	4	4
August.....	4	5	5	6	7	9	10	10	7	6	5	5	5	6	5	4	4	5	6	6	5	3	5	5	6	6	6
September.....	7	8	9	9	10	10	10	11	9	8	6	6	6	6	7	6	6	6	6	6	6	6	6	5	7	8	7
October.....	6	7	8	9	10	9	11	12	11	10	10	8	8	8	8	8	8	8	8	8	7	7	6	6	9	8	8
November.....	9	8	9	8	9	9	10	11	11	10	9	8	9	9	9	9	10	10	10	10	10	10	9	10	10	9	10
December.....	9	10	10	10	11	11	11	12	11	11	11	10	10	10	10	10	11	11	10	10	10	10	11	10	11	10	10

TABLE 4.—Frequency of selected hourly rainfall intensities at Oklahoma City, Okla., 1911-35, inclusive

Month	Total hours with pre- cipitation of any amount	Trace	Intensity group totals						
			0.01 to 0.04	0.05 to 0.09	0.10 to 0.19	0.20 to 0.39	0.40 to 0.79	0.80 to 1.49	1.50 and over
January.....	(a) 1,029	659	268	65	23	10	3		
	(b) 955	533	310	66	33	13			
	(c) 1,983	1,192	578	131	56	23	3		
February.....	(a) 908	553	271	65	15	4			
	(b) 811	421	300	65	14	10	1		
	(c) 1,719	974	571	130	29	14	1		
March.....	(a) 934	515	267	86	47	15	4		
	(b) 875	453	299	85	45	40	13		
	(c) 1,809	968	536	141	92	55	17		
April.....	(a) 860	422	249	84	60	28	15	2	
	(b) 774	317	221	89	75	52	17	3	
	(c) 1,634	739	470	173	135	80	32	5	
May.....	(a) 818	381	197	93	68	50	20	9	
	(b) 808	367	229	76	56	49	22	8	1
	(c) 1,626	748	426	169	124	99	42	17	1
June.....	(a) 587	263	157	57	45	21	9	5	
	(b) 267	238	199	77	74	46	23	8	5
	(c) 1,250	531	356	134	119	67	32	13	5
July.....	(a) 424	209	105	45	30	16	3		
	(b) 375	148	124	30	33	17	11		
	(c) 799	357	229	69	63	33	27	12	3
August.....	(a) 528	247	148	76	38	21	13	1	
	(b) 531	190	151	75	59	35	15	5	1
	(c) 1,059	437	299	134	97	56	28	6	2
September.....	(a) 624	296	181	55	41	34	13	2	
	(b) 684	253	230	76	48	46	26	5	
	(c) 1,308	549	411	131	89	80	39	7	2
October.....	(a) 826	335	265	98	83	22	17	4	
	(b) 734	271	259	75	65	48	13	3	
	(c) 1,560	606	524	173	148	70	30	7	2
November.....	(a) 881	525	262	70	58	18	4	4	
	(b) 829	461	238	67	27	26	7	3	
	(c) 1,710	986	440	137	85	44	11	7	

A STATISTICAL ANALYSIS OF SUMMER STRATUS OVER SOUTH TEXAS

By MARION E. CRAWFORD

[Weather Bureau, San Antonio, Tex., July 1937]

During a study which was begun in an attempt to form a clearer conception of the processes involved in the formation and dissipation of stratus clouds in south Texas some interesting observations were made and are here presented, in the hope that some of the precepts derived will be of use in forecasting the behavior of the stratus cloud.

This study is necessarily based on data available at San Antonio, Tex., which consist chiefly of airplane soundings made at Kelly Field during the summer seasons of 1934-36, inclusive.

During the summer, when the stratus is most common, the normal pressure distribution is such that a slow steady flow of Tropical air which originated in the Trade-wind zone is fed into the eastern and central United States (1). In Texas the invasion of summer Tropical Atlantic (TA) air is sometimes shallow, probably about 1 km, and is overlaid with dry superior (S) air. Although cooling by radiation is somewhat limited by the high moisture content (16 to 18 g/kg at the surface) of TA air, the diurnal temperature range is about 20° F. The surface air is, therefore, usually cooled to within a few degrees of its dew point by morning. This condition associated with a moderate southeasterly wind quite often results in the rapid formation of stratus clouds during the night. Usually the sky is clear prior to the formation of the stratus, which first makes its appearance in thin scattered sheets that gradually thicken into a solid cloud layer with a uniform ceiling. The complete process, from clear to overcast, has frequently been observed to take place within a 5-minute period. Almost invariably a ceiling is left under the stratus deck, seldom if ever decreasing below 400 feet; in addition, visibility is always good under the stratus as ground fog has never been observed

to occur with the summer stratus, so that, in general, aviation difficulties are only moderate. The height of the stratus is usually between 500 and 2,000 feet, varying in thickness from less than 100 to more than 1,000 feet. This uniform layer obtains until after sunrise when it begins to break up, usually resulting in cumulus by noon. Almost invariably this condition occurs unaccompanied by precipitation, fog, or thunderstorms.

During the summer, when the cloud occurs, there is no appreciable change in the weather from day to day, and little change in the specific humidity; thus, eliminating any possibility of it being a frontal or transitional condition. The stratus forms entirely within the moist stratum, usually just below the inversion. The surface of discontinuity between the TA and S air is manifested by a small temperature inversion accompanied by a sharp decrease in specific humidity. Since the occurrence of the so-called "Gulf clouds" or stratus is always associated with a southeasterly wind up to and through the moist stratum, the air is obviously of gulf origin.

Because of the uniform warmth of the waters in the TA source region, the air mass is very moist and quite warm. The conditional equilibrium and high relative humidity observed through the very moist stratum are such that comparatively little forced ascent of the warm current is necessary to bring about a more unstable condition that eventually leads to condensation and cloud formation. This cooling by lifting of the lower strata of air is usually not enough to produce precipitation during the summer. Consequently the prevailing weather conditions in the TA air masses are those of warmth and high humidity accompanied by a good deal of cloudiness during the night and early morning. Visibility is always good under the stratus.

TABLE 1.—Summary of airplane soundings through the moist stratum and to the top of the overlying temperature inversion during June, July, and August 1934-36, inclusive

Amount of low clouds at time of take-off	Number of obser- vations	Surface (206 m M. S. L.)				Base of moist stratum					Top of moist stratum					Top of inversion					Refer. to curve in figure		
		T (°C)	q (g/kg)	R. H. (%)	θ_s (°A)	Altitude m (M. S. L.)	T (°C)	q (g/kg)	R. H. (%)	θ_s (°A)	Lapse Rate	Altitude (M. S. L.)	T (°C)	q (g/kg)	R. H. (%)	θ_s (°A)	Lapse rate	Altitude (M. S. L.)	T (°C)	q (g/kg)		R. H. (%)	θ_s (°A)
Clear.....	96	22.7	16.0	91	342	491	22.9	16.3	84	348	+ .42	733	22.5	16.0	87	348	- .58	1,014	22.8	11.8	61	340	I
Scattered.....	33	23.3	16.8	92	345	617	22.6	17.0	93	350	- .17	790	21.5	16.6	95	349	- .64	1,141	21.3	12.0	67	340	II
Broken to overcast.....	82	24.1	17.8	93	348	560	22.9	17.6	95	351	- .34	877	20.8	16.2	96	348	- .66	1,185	21.4	11.2	62	338	III

The summarized data consist of airplane soundings made during the months of June, July, and August 1934-36, inclusive. Only those observations on days when a moist stratum was present at lower levels, and on which the stratum broke up during the day, were considered. The grouping under the headings of clear, scattered, and broken to overcast, refers to the amount of low clouds present at the time of take-off. Intermediate and high clouds were not considered in this grouping. The accompanying figure shows the temperature and specific humidity data plotted against height.

In consideration of the summarized data and other data at hand, several points are found worthy of enumeration.

1. The temperature lapse rate in the moist stratum, whether clear, scattered, or broken to overcast conditions prevail, lies between 0.58° and 0.66° C. per 100 meters, a

value greater than the saturation adiabatic rate which is approximately 0.40° C. for the high temperatures involved. The moist stratum is, therefore, in conditional equilibrium. The condition is simply that the layer is unstable if saturated, but stable if unsaturated (2). The high relative humidity of the stratum indicates that very little forced ascent is necessary to produce saturation, resulting in instability with respect to saturated air.

2. When the sky is clear of stratus and remains so until after sunrise, even though a moist stratum is present aloft, a ground inversion is usually present indicating very little air movement. This in turn indicates the absence of mechanical turbulence, and hence a clear night.

3. As soon as the air movement increases slightly, the dynamic turbulence prevents the formation of a marked ground inversion; the cooling effect being distributed more rapidly upward. As the air movement becomes stronger,

mechanical turbulence is increased and maintains a thoroughly mixed stratum of air at the ground, topped by a stratus deck.

4. The difference between the temperatures at the base and at the top of the moist stratum for the three conditions is due to adiabatic changes.

5. The moisture distribution is typical of a turbulent layer; that is, the specific humidity is nearly constant at a high value up to the base of the inversion, where it decreases sharply.

6. The relative humidity is high throughout the moist stratum, reaching a maximum at the base of the inversion.

7. As the normal air current of the Texas coast in summer is from the southeast, it might well be expected that the temperature at the base of the moist stratum, approximately 600 m M. S. L., to be 23° or 24° C. as the result of adiabatic change in temperature with elevation, because the sea-surface temperatures during the warmest season average over the entire Gulf of Mexico and the Caribbean Sea region close to 28° or 29° C.

8. That radiational cooling which occurs near the upper surface of the moist stratum is not the predominating factor in the formation of the stratus is evident as no pronounced cooling takes place at the upper surface of the moist stratum to cause instability with respect to dry air, leading to the formation of the stratus by a convective process. There is very little steepening of the lapse rate through the moist stratum after the stratus forms. This should not be interpreted to mean that radiation does not play a part. Perhaps occasionally, in individual soundings where the lapse rate in the moist stratum was very near the dry adiabatic rate before the stratus formed, it is the predominating factor (3); but generally such a steep lapse rate does not prevail.

9. It was noted that, when the sky is clear of stratus, the saturation level of the base of the moist stratum is above the base of the inversion. Scattered stratus is present when the saturation level is at or very near the base of the inversion; the amount of the scattered stratus is usually quite variable. With broken to overcast stratus the saturation level of the base of the moist stratum is considerably below the base of the inversion.

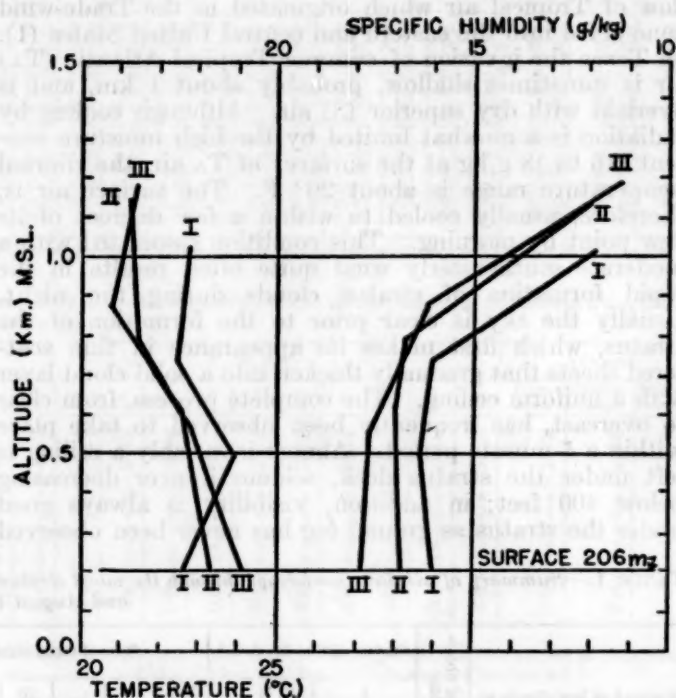
10. All soundings in which the stratus is present are characterized by an overlying dryer and warmer air. The very stable layer of air separating the two strata acts as a lid through which little mixing of air takes place; and, also, the turbulence, produced by the surface over which the air current is passing, usually ceases near this height. This leads to the somewhat paradoxical statement that the drier the overlying air the greater the probability of stratus, provided, of course, that there is an extremely moist stratum of air next to the ground.

Thus, a logical explanation of the inversion should precede that of the stratus formation. Since in Texas the invasion of summer T_A air usually occurs with dry S air aloft, the presence of a small temperature inversion between the two air strata is to be expected as the S air averages a few degrees higher than T_A at intermediate levels. Occasionally this inversion is strengthened by extremely warm S air aloft. It is also slightly intensified at night by the outgoing radiation from the top of the moist stratum.

When the S air is replaced by T_A air, no inversion is present to limit the distribution of the terrestrial radiational cooling; and it is therefore carried to upper levels, resulting in a more moderate lapse rate through the extremely moist stratum. Consequently the probability of stratus is lessened as conditional equilibrium is not likely

to occur in the lower levels, because of thermal stability in the air mass.

Returning to the effect of the inversion: it is found that when the saturation point is reached and stratus forms under the inversion, the outgoing radiation at night from the upper surface of the cloud layer will be that of a "black" body, and will follow the well-known Stefan's law $R = cT^4$ where c is a constant characteristic of a black body, T the absolute temperature, and R the radiation (4). But the outgoing radiation from the warmer and drier air immediately above the cloud layer will be that of a "gray" body. The radiation from moist air R' depends largely on the amount of water vapor present according to Brunt (5). The lapse rate through the moist stratum indicates that no pronounced cooling takes place at the top of the moist stratum after the stratus forms, as it is not appreciably steeper with an overcast than when the sky is clear of stratus (figure 1).



The conclusion is reached that the temperature inversion is due to the surface of discontinuity between T_A and S air, strengthened slightly by radiation from the upper surface of the moist stratum.

This satisfactorily explains the presence of the early morning temperature inversion above the moist stratum and its relatively small magnitude, but not the formation of the stratus.

Notwithstanding the fact that a minimum of cloudiness occurs simultaneously with a maximum of wind (surface) movement, and vice versa (6), the theory is supported that mechanical turbulence is the predominant factor in producing the cloud. It is not so well known that the maximum wind movement during the early morning hours is ordinarily found at an elevation of from 400 to 600 meters above the surface (7), i. e., 600 to 800 M. S. L. at San Antonio. This (gradient) wind is usually over twice the velocity of the surface wind. Therefore, mechanical turbulence must be present at night when there is a rapid increase in wind velocity with elevation. In the absence of much wind movement mechanical turbulence is proportionately lessened. The turbulence is not always suffi-

ciently strong to be termed as such by pilots, but is active enough to keep a thoroughly mixed stratum of air near the ground.

In addition to increasing the turbulent motion the stronger southeasterly wind brings in air of higher specific humidity from the Gulf, along with a faster rate of cooling caused by forced ascent up the coastal slope.

Since the very moist stratum of air is present much of the time regardless of whether or not stratus forms, the necessary factor, i. e., mechanical turbulence, for its formation is supplied by an increased wind movement, especially just above the surface. As the lapse rate through the moist stratum lies between the dry and saturation adiabatic rates, an element lifted upward will first encounter resistance to its vertical motion, because it would cool with altitude at the faster dry adiabatic rate; after condensation it would follow the saturation adiabatic rate, which is slower than that of the surrounding atmosphere, and pass from stable to unstable at the equilibrium level, after which it would continue to rise to the base of the inversion because it would then be lighter than its environment. This results in the formation of the observed uniform layer of stratus clouds. This type of temperature distribution (through the moist stratum) is called convective instability, the conditions being (a) a sufficient amount of moisture in the air so that the moving element becomes saturated soon enough to follow a saturation adiabatic line which intersects the prevailing lapse rate curve, and (b) a strong enough mechanically-produced lifting to overcome the stabilizing forces at the lower levels and carry the element to the equilibrium point (8).

Convective instability is also definitely indicated as the equivalent potential temperature decreases with height within the layer.

The influence of nocturnal radiation is evident because the stratus forms at night. The principal cooling seems to take place by terrestrial radiation and, in the absence of a moderate air movement, causes a ground inversion. Therefore, when a marked ground inversion is present, no stratus forms because of the lack of turbulence. Other factors indicated in the summarized data are much the same as when stratus is present; but mechanical turbulence is evidently absent as it would prevent the formation of the ground inversion.

As soon as there is the slightest air movement, the dynamic turbulence prevents the formation of a marked ground inversion; the cooling effect being distributed more rapidly upward (9). As soon as the air movement becomes stronger, the dispersion of the air cooled near the ground becomes such that ground inversions can no longer exist. The condition that prevents or eradicates ground inversions, therefore, facilitates the formation of stratus. Consequently the two conditions, i. e., a marked ground inversion and a stratus deck, are seldom observed in the same sounding. It should be noted that the upper inversion is present even when the sky is clear and conditions are calm, and is not the result of the ground inversion being forced upward as the wind velocity increases.

Although no summary of soundings is available for proof, it seems logical to assume that the breaking up of the stratus into cumulus is by convective turbulence brought about by a steeper lapse rate near the ground caused by insolation heating of the air near the ground during the daytime as it moves inland from the Gulf coast. As previously stated, in Texas the invasion of summer TA accompanied by dry S air aloft makes thunderstorms in TA air much less likely than farther east; the decrease in equivalent potential temperature aloft indicates much potential instability but in the absence of much moisture it cannot be realized very often except from the marked vertical displacement with passage of cold fronts. Thus, only cumulus results from the stratus with a tendency to dissipate in the early afternoon. Complete dissolution, of course, depends on the dryness of the overlying S air.

Unfortunately, upper air wind velocity data were not readily available for correlation with the airplane soundings.

Summary.—Investigations of the South Texas stratus by means of airplane soundings at San Antonio, Texas showed that the lapse rate through the moist stratum of air which produces the stratus lies between the dry and the saturation adiabatic rates, and it is overlaid with a drier and warmer air mass (S) separated by a small inversion. Nocturnal radiation cools the lower layers of air and brings about a more nearly saturated condition near the ground. When the moist stratum remains free of stratus, a marked ground inversion is present, indicating little air movement and, thus, the lack of turbulence. The presence of a pressure distribution favorable for the establishment of a comparatively strong southeasterly gradient wind not only brings in air of higher moisture content; but, also, produces the necessary mechanical turbulence for the formation of stratus. During the night, when the air movement increases sharply with elevation, turbulence should be expected. Mechanical turbulence is apparently the predominating factor in the formation of the stratus as it is apparently the only significant factor present in the stratus formation which is absent when the sky remains clear.

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FOG FORECASTING FOR FIRE CONTROL IN SOUTHERN CALIFORNIA

By ARVY A. LOTHMAN

[Weather Bureau, Pasadena, Calif., September 1937]

Summer stratus or, so-called, California "high fog" plays an important role in fighting forest fires in the littoral region of southern California. If fog is expected on a going fire, men may be released, thereby reducing the cost of suppression; the fire lines may be drawn in closer to the actual fire, thereby reducing the actual acreage of burn. For these reasons it is advantageous to have reliable forecasts as to whether or not fog will occur over small local areas.

The forecasts of fog may have to be made for territory extending from the Mexican border to the Monterey-San Luis Obispo County line, for elevations from sea level to nearly 4,000 feet, extending from the coast to about 60 miles inland. Pasadena, where the practicability of fog forecasting for fire control was tested, lies at an elevation of 850 feet above sea level, about 25 miles from the coast at the base of mountains which rise to over 5,000 feet.

An explanation of the theory of formation by convection of this summer fog has been given by Petterssen.¹ The maintenance of the inversion necessary for the fog to form was shown to be due to differences in the radiative qualities of different air masses by Bowie,² and was later amplified by Blake³ and Petterssen.

Explaining the processes involved in the formation of the fog, Petterssen says:

The air which produces fog is unstable and the fog or stratus forms because of convection under the temperature inversion separating the Pacific air from the dry air aloft. Outgoing radiation from the top of the moist layer is effective in maintaining the temperature inversion and the instability of the air.

The surface air particles are forced to rise due to the instability of the air, and fog is formed if the condensation level of this air is below the base of the temperature inversion. Figure 1 shows a typical temperature-altitude curve which favors fog formation.

A practical method of using the theory outlined by Petterssen has been worked out at the Pasadena office for forecasting the extent to which the fog will form inland. The forecasts are for use in forest fire control and are made every evening. Therefore the periods covered by the fog forecasts are for that night and the following morning.

Since fog may form when the convective condensation level of the surface air particle is lower than the base of the inversion, it is first necessary to determine the height of this base which will prevail during the forecast period. Although it is admitted that a more accurate method, such as an aerographic sounding, should be used to determine the air structure just prior to making the forecast, the height of the base of the inversion can be closely estimated by various indirect methods. For example: (1) Ceilings are reported from airway stations along the coast. If fog is just forming or has just formed, reports from these sources will give an estimate as to its height. (2) Changes that have taken place in the air structure since the morning aerographic soundings were taken at San Diego and Long Beach may be estimated. Changes in wind direction in the air below the inversion are the primary reasons for changes in the height of the base of the inversion, according to Petterssen.

The next consideration is the possibility of a change in the air mass, during the forecast period, which would change the air structure. This can be determined from the synoptic chart; however, in southern California during the summer very few changes of air mass take place.

Since no fog can form above the base of the inversion, out attention is directed to all the area lying below this elevation. From surface reports of temperature, relative humidity, and pressure, the mixing ratio of the air in the area is determined. On a pseudo-adiabatic chart, from the point where the saturation mixing ratio line (corresponding to the mixing ratio of the surface particle) crosses the base of the inversion, the dry adiabat is followed down to the surface elevation of the forecast area; this will then give the critical temperature, i. e., the temperature to which the surface air must be cooled before fog will form.

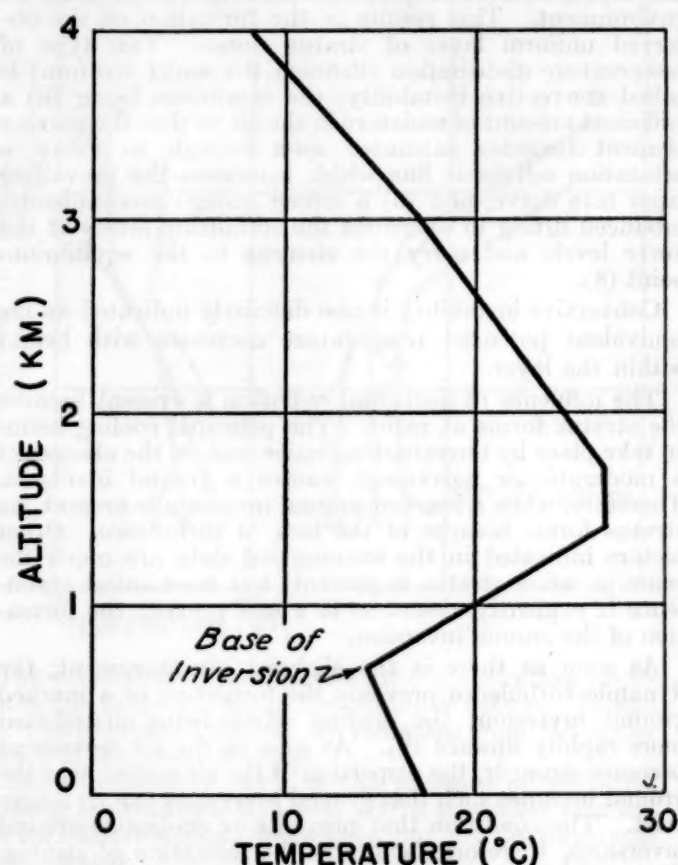


FIGURE 1.—Temperature-altitude curve, July 20, 1937, Long Beach, Calif.

The next consideration is the probable minimum temperature that will be reached during the forecast period. Fog should be predicted in all areas where the temperature is expected to fall below the critical temperature.

In using ceiling heights as reported by coast airway stations for determining the base of the inversion, it has been found that in some cases the reported ceilings are so low that they cannot be explained as due to changes in the air mass subsequent to the morning aerographic soundings taken at San Diego and Long Beach. The low base of the inversion would indicate that fog could occur only

¹ On the Causes and the Forecasting of the California Fog, Sverre Petterssen, *Journal of the Aeronautical Sciences*, vol. 3, July 1936.

² The Summer Nighttime Clouds of the Santa Clara Valley, California, Edward H. Bowie, *MONTHLY WEATHER REVIEW*, vol. 61, February 1933, pp. 40-41.

³ Further Conclusions From Additional Observations in the Free Air Over San Diego California, Dean Blake, *MONTHLY WEATHER REVIEW*, vol. 62, June 1934: pp. 195-199.

along the immediate coast at low elevations; however, as shown by Petterssen, in several cases the low ceiling was due to a double inversion that produced fog in the morning some time after insolation had destroyed the small lower inversion.

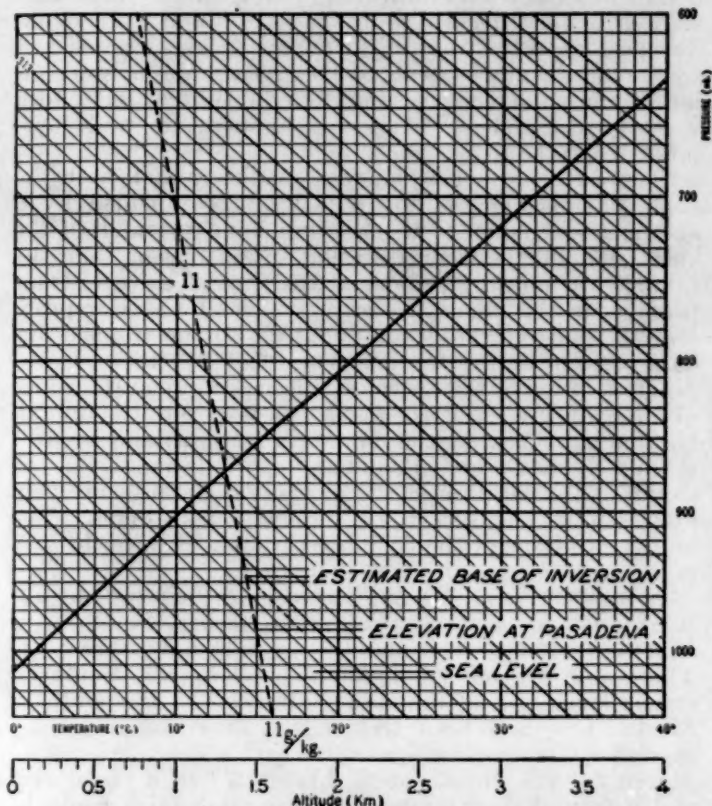


FIGURE 2.—Diagram showing method employed to calculate the temperature necessary to produce fog at Pasadena on the evening of July 18, 1937. The solid diagonal line is a pressure-height curve to be used in conjunction with the lower horizontal scale for determining altitude.

An example of a double inversion at Pasadena occurred on the morning of July 19, 1937. When the forecast was made the previous evening, the base of the inversion was estimated to be about 600 meters, as determined from the morning aerographic observations. The surface-mixing

ratio at Pasadena was calculated to be about 11g/kg. From an altitude of 600 meters (see figure 2) on the 11g/kg curve of mixing ratio, projecting down along the dry adiabat to the surface elevation of Pasadena a temperature of 17.8° C. was found necessary to produce fog. The minimum temperature for the next morning was expected to be several degrees lower than that; therefore fog was expected to form.

At 7:50 p. m., July 18, the airway reports indicated temperatures from 17.9° to 18.4° C. and mixing ratios of about 11g/kg on the coast. Projecting the surface sea level temperature upward along the dry adiabat to the 11 curve of constant saturation mixing ratio would indicate a convective condensation level between 300 and 350 meters. Yet no fog was reported overhead by any of the stations, which would indicate that the base of the inversion was below 300 meters. Some of the stations reported low fog banks seaward, which would also indicate the base of the inversion to be very low. Since there was no justification for such a low base for the inversion, as shown by the synoptic situation, the only conclusion to be drawn was that a double inversion existed in the air. This proved to be true because by 4:50 a. m., July 19, fog was reported all along the coast, with ceilings ranging from 150 meters to 240 meters. No fog had occurred at Pasadena or Burbank up to this time. At 6:30 a. m., 1 hour and 45 minutes after sunrise, when the lower inversion was destroyed, fog formed at Pasadena and continued until about 7:45 a. m. Burbank reported dense fog at 6:50 a. m.; and the ceiling at San Diego had risen to about 400 meters.

A plotting board was constructed to aid in making quick analyses for fog forecasting: On one side a Millar nomogram⁴ is mounted under celluloid for determining the surface mixing ratio. On the other side a pseudo-adiabatic diagram was mounted to be used in determining the temperature necessary to produce fog.

The method of fog forecasting presented in this article is considered to be reliable whenever the height of the base of the inversion can be closely determined, and when a fall in temperature below that necessary to produce fog is predictable. In the short period of 4 months' trial at Pasadena it has been highly successful.

⁴ Rapid Methods Of Calculating The Rossby Diagram, F. Graham Millar, Bulletin of the American Meteorological Society, October 1935, pp. 229-233.

SYNOPTIC ANALYSIS OF THE SOUTHERN CALIFORNIA FLOOD OF MARCH 2, 1938

By CHARLES H. PIERCE

[Weather Bureau, Washington, June 1938]

On the morning of March 1, a deep low with a wide-open warm sector was centered at latitude 34° N., about half way between San Francisco and the Hawaiian Islands.

The warm front of this low was peculiar because instead of extending southward, as do most warm fronts of the Pacific lows in this locality, it extended east-southeastward and was connected to a cold front of a preceding system which had passed inland on the previous day. This cold front extended through southern California and passed into Mexico during the day, giving California temporary clearing that afternoon.

In the meantime, the low which was centered at 34° N. and 140° W. was occluding and moving rapidly northeastward, being centered at approximately 39° N. and 132° W. at 4:30 p. m. (all times Pacific Standard). In spite of the rapid occlusion near the center, there was still a very

extensive warm sector with a supply of moist Tropical Pacific air a short distance southwest of southern California. With the low moving so rapidly northeastward, it meant that the cold front that had passed southward of the international boundary would soon change its direction of motion, and start returning as a warm front.

Late that night rain was already falling along the coast from the overrunning warm air to the southwest.

At 4:41 a. m. March 2, the low center was off the Oregon coast with an occluded front, north of Marshfield and Roseburg, Oreg., which curved sharply southwestward into California. The position of the fronts and the pressure distribution over California at 4:41 a. m. is shown by the map of that time for March 2.

In the following 6 hours the cold and occluded fronts advanced rapidly eastward with the warm front moving

with equal speed to the northeast. The position of the fronts and pressure field at 10:41 a. m. is shown on the map.

The warm-front passage was not noticeably marked along the coast and in the valley stations, although in most cases the wind shifted from southeast force 4 Beaufort, to south or south-southwest force 5 Beaufort, accompanied by a temperature and dew-point rise of 3° to 6°. Burbank, for instance, shifted from southeast 15 miles per hour to south 13 miles per hour with temperature and dew point rising from 56°/56° to 61°/61° within 35 minutes from 8:41 a. m. to 9:15 a. m. The front passage was more marked at the higher stations. Sandberg shifted from south 26 to south-southwest 48 with temperature and dew point increasing from 45°/45° to 48°/48° at 10:41 a. m. and to 50°/50° within the next hour. Palmdale shifted from north 8 to west-southwest 43 with the temperature and dew point jumping up from 50°/50° to 58°/55°. It may have been that some of the cold air was trapped on the southern slope of the mountains, but it seems likely that this air was mixed with the Tr air under the strong turbulent conditions that prevailed throughout this area.

One of the most interesting features of the storm was the rainfall pattern before and after the passage of the warm front. Table 1 shows the hourly rainfall for seven stations in the Los Angeles area. Los Angeles, Van Nuys, and Claremont are valley stations, while the others are located along the slope of the Sierra Madre Range and are termed mountain stations. The location and the elevations of these stations are shown in figure 1.

It will be noted that during the hours before the warm-front passage in the early morning, the rainfall for all stations was about equal with an hourly rate between .30 and .75 of an inch. After the warm front had passed to the north of the Sierra Madres, there was a noticeable increase in the hourly rate for the mountain stations with continuous heavy precipitation amounting to over 1.00 inch per hour in most cases. On the other hand, the rainfall at the valley stations did not increase at all, but showed a shower type of precipitation that one would expect in the conditionally unstable tropical maritime air. The hourly rates at Los Angeles seen in the table from 10:00 a. m. to 4:00 p. m. indicate this.

The heavy rainfall for the mountain stations may be explained by the more rapid lifting of the Tr air against the southern slope of the mountain. As Daingerfield states in his paper on this storm, the Sierra Madres acted as a permanent front to the air in the warm sector. However, the front caused by this mountain range was much steeper than the normal warm front between two air masses. The rough cross section through Los Angeles and Palmdale, figure 2, indicates the difference in stream lines of the tropical air before and after the front passage. At 4:41 a. m. all the stations were within the cold air, and the Tr air was being lifted along the front at the same rate over all the stations. Six hours later, after the front had passed, the air flow was such that the lifting of the Tr

air was very pronounced on the southern side of the ranges, resulting in the heavy rain on these slopes.

The frontal motions decelerated late in the morning and during the afternoon. The cold front passed Bakersfield before 11:41 a. m. with the temperature dropping 7° and a shift of wind from Southwest to Northwest. Sandberg showed a very decided front passage about 1:41 p. m. The passage of the front in the valley stations was masked by the topography as usual, although there was a diminishing of the wind velocity and a slight shift of wind to a westerly component. Also the temperature and dew-point dropped 3 to 5 degrees.

There was no marked increase in the rainfall with the cold-front passage, although it was accompanied by a shower about equal to the heaviest hourly rainfall of the storm for the particular station. The reason that the rainfall was not any heavier at the time of the cold-front passage, in the mountains anyway, was because it probably did not offer any additional lift to the tropical air. The passage of the front was marked by the eastward progress of the final shower, as will be seen upon the study of table 1. Following the passage of the front, the rainfall became light even at the mountain stations, and by 5:41 p. m., Burbank and Palmdale reported breaks in the clouds. The location of the fronts and the pressure field at 3:41 p. m. and 4:41 p. m., is shown on the maps. The hourly positions of the cold front from 2:41 p. m. to 5:41 p. m., inclusive, is shown also in figure 1.

In review then, the synoptic causes of the record breaking rainfall for southern California during the storm of March 2, 1938, were mainly the following three: (1) There was a good supply of moist Tropical Pacific air over a large area of the ocean southwest of the southern coast. This had been transported into this region by several waves moving across southern California prior to March 2. (2) The storm of March 2 had a circulation and a frontal set up such that excessive rains could be produced. (3) The orographic effect produced rapid lifting of the warm moist air.

In the first place the storm had a steep pressure gradient which rapidly transported Tropical Pacific air northeastward from an extensive warm sector. This air moved almost normally to a steep warm front surface which produced in the neighborhood of 3 to 5 inches of warm-front rains at the hourly recording stations.

After the warm-front passage, convergence within the airmass caused by the rapid transport of air into the low-pressure area and convergence caused by deepening of the low in this area produced unstable conditions of the air which would have probably caused heavy showers even over flat country. However, orographic conditions in the form of the Sierra Madre Range directly across the path of this rapidly-moving conditionally-unstable air was the main factor in the excessive rains. Then added to this, the stream of Tropical Pacific air prevailed unabated for 6 hours across this region before it was cut off by the passage of the cold front.

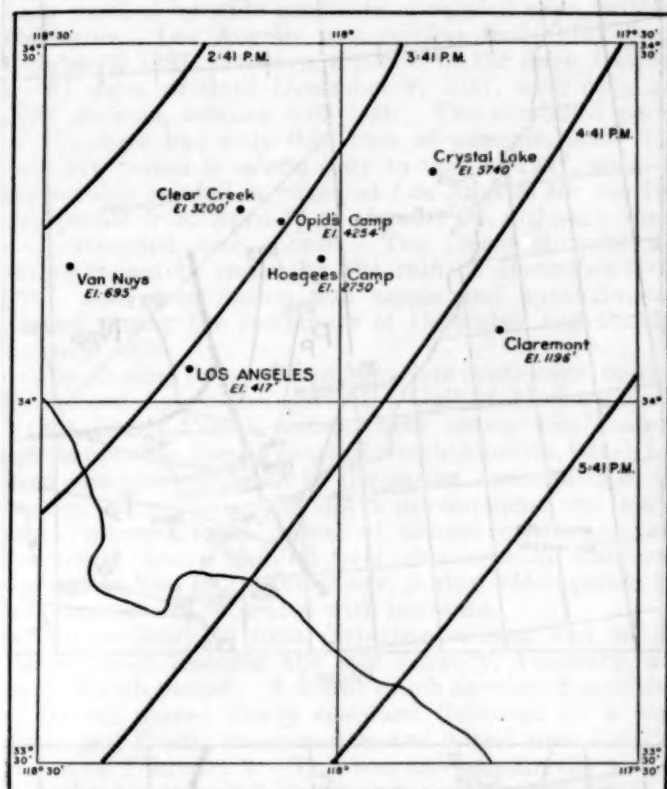


FIGURE 1.—Map showing hourly progression of cold front from 2:41 to 5:41 p. m., March 2, 1938, in relation to location of recording rainfall stations in Los Angeles area.

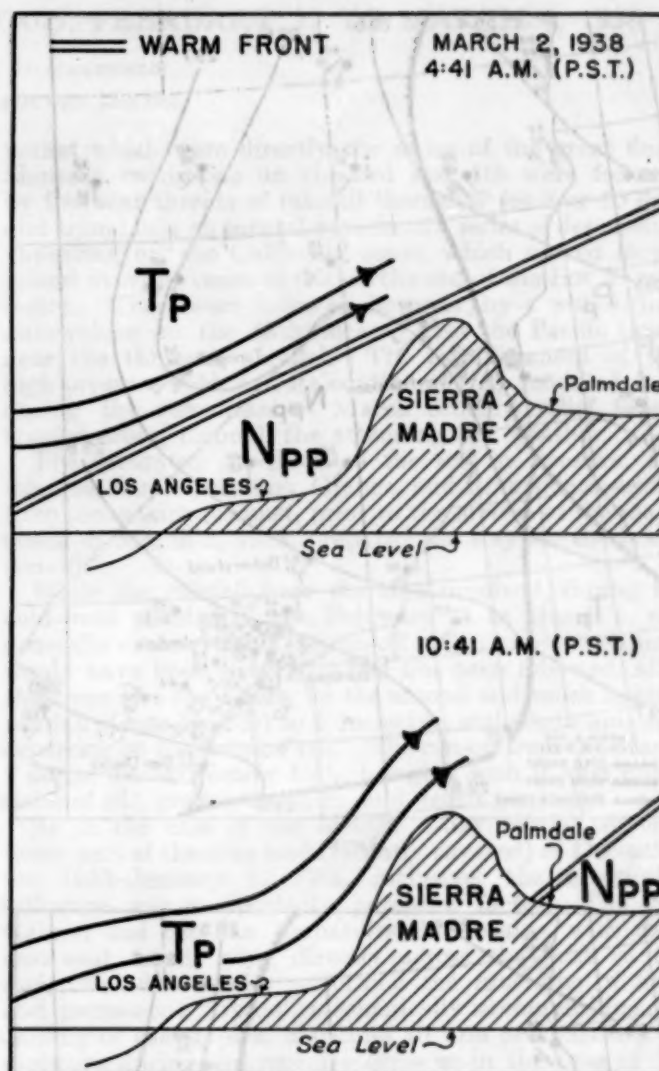


FIGURE 2.—Cross section extending through Los Angeles and Palmdale, Calif., showing streamline flow of T_p air before and after the warm front passage.

TABLE 1.—Hourly precipitation amounts, 9 p. m., March 1, to midnight, March 2, inclusive

Station	March 1				March 2												March 2												Total
	P. M.				A. M.												P. M.												
	9	10	11	Mid- night	1	2	3	4	5	6	7	8	9	10	11	Noon	1	2	3	4	5	6	7	8	9	10	11	Mid- night	
Claremont, No. 92.....				0.10	0.21	0.10	0.10	0.17	0.29	0.45	0.45	0.58	0.43	0.39	0.17	0.23	0.23	0.50	0.40	0.24	0.22	0.44	0.09		0.01		0.01		5.81
Clear Creek, No. 47A.....				0.10	.25	.22	.08	.15	.35	.37	.38	.41	.75	.88	1.50	1.00	1.40	1.40	1.55	1.20	.94	.55	.20	.23	0.13	.06	0.08	.05	14.11
Crystal Lake, No. 283A (East Pine Flat).....			.03		.15	.24	.12	.21	.23	.33	.46	.35	.72	.79	.76	1.07	.87	1.48	1.57	1.50	(1)	2.27	.36	.11	.17	.31	.07	.18	14.49
Hoegues Camp, No. 60A.....		0.01	.13		.33	.15	.22	.36	.42	.59	.49	.72	.53	1.17	1.20	.82	.95	1.29	1.11	1.31	1.47	.79	.20	.08	.27	.01	.11	.05	14.84
Los Angeles.....	T	.01	.15		.24	.10	.07	.14	.44	.68	.34	.77	.54	.59	.45	.02	.33	.08	.41	.19	.42	.20	.06	T	.05				6.28
Opids Camp, No. 57 ¹.....			.01	.13	.27	.13	.24	.39	.40	.56	.41	.75	.54	.96	1.67	.92	1.09	1.37	1.45	.38	1.42	.90	.21	.07	.19	.12	.07	.12	14.86
Van Nuys, No. 15.....			.02	.10	.20	.08	.08	.24	.38	.39	.38	.39	.32	.44	.29	.19	.60	.45	.38	.39	.14	.10	.06		.03				5.68

¹ Included in next hour. Gage at capacity during interval. Standard gage reading used.

² Automatic gage reached capacity at 2:15 p. m. Interpolation made from intensity gage readings for the remaining hours.

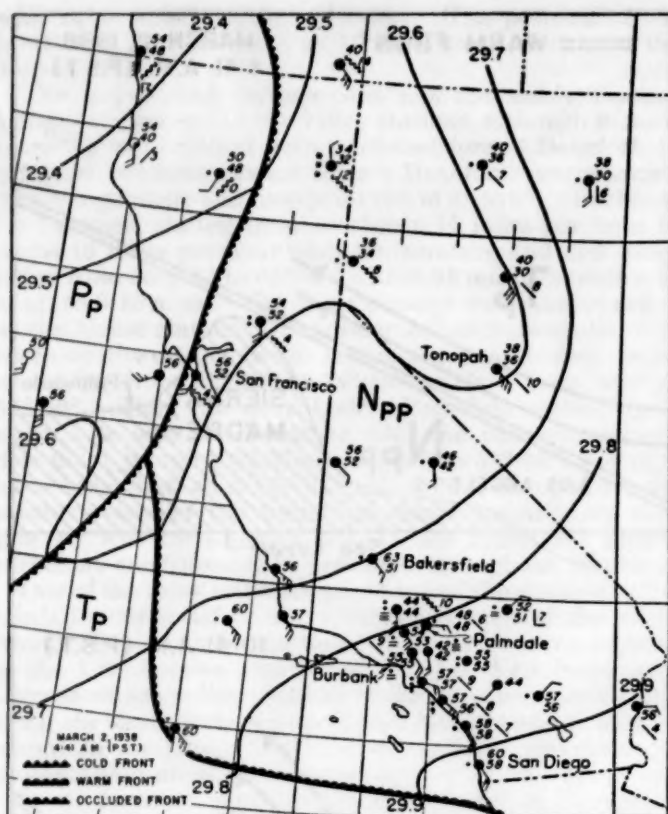


FIGURE 3.

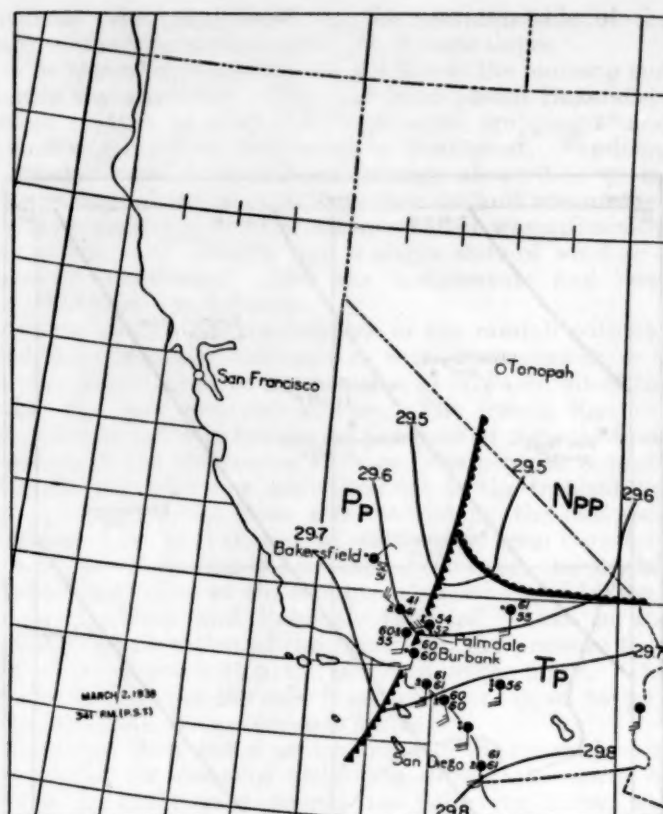


FIGURE 5.

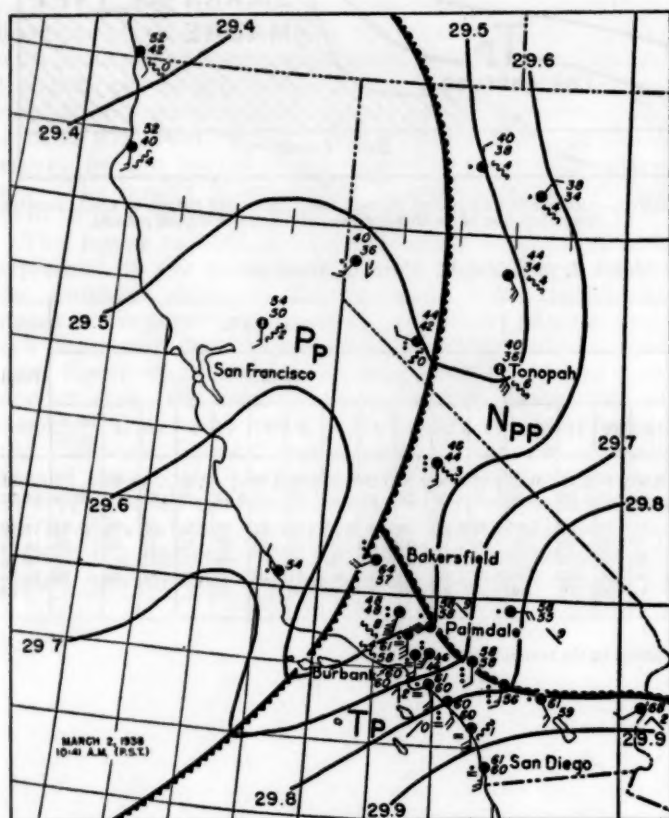


FIGURE 4.

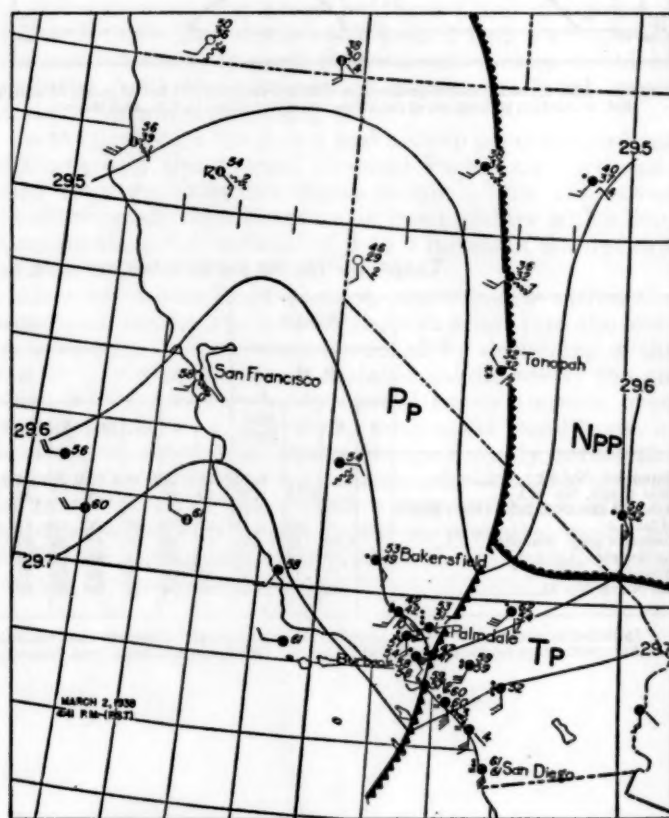


FIGURE 6.

SOUTHERN CALIFORNIA RAIN AND FLOOD, FEBRUARY 27 TO MARCH 4, 1938

By LAWRENCE H. DAINGERFIELD

[Weather Bureau, Los Angeles, Calif., June 1938]

The season of 1937-38 (beginning July 1, 1937) has been marked by wide contrasts in rainfall over southern California. Los Angeles was rainless from May 31 to October 2, 1937, inclusive, a period of 125 days, followed by 67 days, or until December 8, 1937, with only two light showers, totaling 0.03 inch. The combined period of 192 days had only 0.03 inch of precipitation. This long dry period is second only to that of 1927, when no measurable rainfall occurred at Los Angeles for the 197-day period from April 13 to October 26, although traces were recorded each month. The recent drought was rather definitely ended by the rain of December 9-12, 1937, and precipitation was ample and approximately normal during the remainder of December and through January 1938.

The closing days of January, however, were marked by intense disturbances over the Gulf of Alaska and adjacent North Pacific waters, with strong southeasterly trends near the Pacific coast of North America, which had been absent or deficient in the earlier depressions of the season. This change in storm development and movement ushered in a period of almost continuous and frequently heavy rainfall over this area of California during the first half of February, during which period the soil became well saturated with moisture.

The tendency to form disturbances near and off the Pacific coast featured the late January, February, and early March period. A storm which developed northeast of Hawaii moved slowly eastward (followed by a well-developed Pacific high) and moved inland near the Bay region on February 9. This was an exceptionally violent disturbance, attended by precipitation throughout California, heavy over the northern part of the State, and high winds and gales over most coastal districts and inland to and beyond Sacramento.

A series of North Pacific and Gulf of Alaska depressions prevailed from February 26 to March 4, 1938, extending their maximum sphere of influence hundreds of miles farther southeastward than normally over the Pacific coast area. On February 27, a rather shallow disturbance moved slowly in over the southern California coast attended by a general light rain on the 27th, and intermittently through the 28th. During the night of February 28-March 1, heavy rain occurred as the result of the passage of a cold front which moved in from the northwest. No general rain occurred after this frontal passage until March 2, with the arrival of a more intense disturbance. This disturbance likewise developed northeast of the Hawaiian Islands and while the center moved to the Oregon coast, the region of greatest intensity took place over southern California. Warm-front action and a pronounced orographic effect produced the greatest intensities and amounts of precipitation of the entire storm

period which were directly the cause of the great flood. Showery conditions on the 3rd and 4th were followed by frequent threats of rainfall thereafter for 9 or 10 days and actual rain on several days from a series of depressions appearing off the California coast, which moved slowly inland over the coast to the northward of the Los Angeles region. These were followed, however, by a well-defined anticyclone on the 13th, located over the Pacific Ocean near the thirtieth parallel. The establishment of this high pressure field, and its continuance in modified form during the remainder of March brought relief to the flooded areas, through the attending fair weather.

The saturated condition of the soil in Ventura, Los Angeles, San Bernardino, Orange, and Riverside counties, from mountains to coast, prior to the arrival of the major storm of March 2, 1938, prepared the way for the heavy run-off.

While the rainfall over the area involved, during the cold-front passage of late February 28 to March 1, was generally excessive and the run-off rather marked, damage would have been small if it had not been followed, after the lapse of a few hours, by the second and much heavier rainfall of late March 1 to 2, inclusive, with slight amounts occurring on the 3rd and 4th. The run-off from the March 2 storm was extremely high, bringing with it vast quantities of silt, gravel, boulders, and debris generally.

As in the case of the historic 3-day rainfall (over a lesser part of the area more recently covered) of December 30, 1933-January 1, 1934, inclusive, the orographic influence was a decidedly potential factor. The San Gabriel and the San Bernardino Mountains, with their east-west trend, lying directly across the path of the moisture-laden winds, performed the functions of fixed and permanent "fronts" mechanically accomplishing the chilling of the tropical maritime air and precipitating its moisture during the recent storms as in the case of the great 3-day storm of 4 years ago. Just as the 3-day storm was a record breaker for the period and area involved, so was the recent 5-day rainfall the heaviest known for the period involved—at least since accurate measurements have been generally available.

In the recent storm period, the greatest recorded amount, 32.20 inches, occurred at Kellys Kamp in the San Gabriel Mountains at an elevation of 8,300 feet. Also, in the same mountains, Hoeges Camp, elevation 2,650 feet, reported a total of 30.08 inches; this same station received the greatest amount in the 1934 New Year's storm (19.91 inches). In the San Bernardino Mountains, Lake Arrowhead, near the headwaters of Deep Creek, which will be referred to later, at an elevation of nearly 5,000 feet, reported 30.49 inches. A considerable number of mountain stations received between 20 and 30 inches of rain as shown in table 1.

TABLE 1.—Precipitation data (inches and hundredths), Feb. 27 to Mar. 4, 1938, inclusive, for Ventura, Los Angeles, Orange, San Bernardino, and Riverside Counties

[Precipitation for 24 hours ending near sunset unless otherwise indicated]

Station	Latitude	Longitude	Elevation above m. s. l.	February		March				Greatest		Storm total
				27	28	1	2	3	4	1 hour	Date	
Action (near)	34 30	118 16	3,075	0.54	0.23	0.89	3.05	0.81	0.03			5.55
Aliso, No. 62 (Orange County) ¹	33 43	117 50	62	.30	1.00	.96	1.27	2.40	.10			6.03
Alder Creek	34 20	118 03	4,050	1.24	.93	1.62	7.64	1.42	.17			13.02
Altadena	34 12	118 08	1,328	1.86	2.75	2.18	8.33	.62				15.74
Anaheim (Orange County) ¹	33 50	117 55		(²)	1.57	1.03	2.13	2.98	.02			8.63
Arcadia	34 08	118 01		1.60	2.73	2.35	7.30	.57				14.55
Arroyo Seco	34 13	118 11	1,530	1.26	2.62	2.62	8.10	1.00				15.60
Arroyo Seco County Forestry	34 12	118 11	1,155	1.65	2.83	3.23	8.47	1.36				17.54
Arroyo Sequis	34 05	118 33	1,155	.42	1.89	2.74	5.98	.97				12.00
Avalon (Catalina) ¹	33 21	118 19	30	.49	1.62	1.22	1.45	2.18	.03			6.99
Azusa	34 08	117 54	602	1.33	2.25	2.30	6.72	.84				13.44
Azusa Plant	34 09	117 55	675	1.25	2.34	2.41	7.00	.96				13.96
Backus Ranch	34 36	118 12	2,620		.86	.65	1.74	.32				3.57
Baldwin Park No. 182	34 05	117 58	378	1.60	1.60	1.71	5.68	.87				11.46
Banning	33 55	116 53	2,330		1.65	1.27	2.24	2.70	.25			8.11
Beaumont ¹	33 52	116 55	2,580	.63	1.28	1.76	1.01	4.08	.33			9.09
Beaumont (near) ¹	33 55	116 55	3,040	.45	.95	1.75	.90	6.25	.46			10.76
Bell, No. 192	33 50	118 11	100	1.65	1.31	1.85	4.60	.43				9.83
Bell, No. 6 (San Dimas X)	34 11	117 48	2,850	(²)	6.18	.62	9.40	.92	.08	.40	2	17.20
Bell 3100 (San Dimas X)	34 12	117 46	3,100	1.50	4.80	.22	5.43					19.04
Bell-Volfe (San Dimas X)	34 10	117 48	1,880	1.56	6.38	.68	9.32	1.10		.39	2	11.83
Beverly Hills, No. 228B	34 05	118 24	255	1.42	2.24	1.79	6.08	.30				17.40
Bennett Ranch ¹	34 08	117 28	1,750	(²)	5.50	2.15	(²)	(²)	9.75			26.95
Big Bear Lake Dam	34 14	116 59	6,800	4.96	3.39	1.54	15.06	2.00				14.97
Big Dalton Dam, No. 223	34 10	117 49	1,575	1.24	3.66	3.42	6.58	.07				17.55
Big Pines County Park	34 23	117 41	6,800	2.00	2.59	1.68	6.80	4.48	.30			20.36
Big Tujunga Dam no. 1	34 17	118 12	2,050	1.20	3.28	3.00	10.83	2.05		{ 2 hr. } 2.30	2	8.65
Blum Ranch (near Acton)	34 27	118 09	2,900	1.17	.27	.91	5.82	.48				13.73
Brand Park, No. 210B	34 11	118 16	1,250	1.33	2.08	2.54	7.02	.76				18.53
Briggs Terrace, No. 373	34 14	118 14	2,616	1.18	3.36	3.15	8.88	1.10	.86			7.01
Burbank (Airport) ¹	34 11	118 18	650	.07	1.26	1.92	.70	2.85	.21			12.77
Burbank, No. 226	34 11	118 18	665	1.41	1.79	2.43	6.43	.71				9.12
Calabasas, No. 5	34 09	118 38	950	.93	.96	1.70	5.07	.46				14.77
California Institute, No. 303	34 08	118 08	763	1.62	2.72	2.27	5.60	2.56				23.23
Camp Baldy	34 14	117 39	4,320	(²)	3.95	4.50	12.00	2.78		1.78	2	22.09
Camp Rincón, No. 349	34 14	117 52	1,500	1.30	3.89	2.65	(²)	14.00	.16			9.51
Carbon Canyon, No. 20 (Orange County)	33 58	117 46	1,150	.15	1.95	1.76	2.80	2.70	.15			7.56
Cemetery (Orange County) ¹				.28	.91	1.61	1.44	3.11	.21			10.68
Chatsworth Patrol Station	34 15	118 37	865	.53	1.19	2.06	6.10	.80				9.90
Claremont	34 07	117 44	1,196	.70	1.25	1.63	5.73	.59				23.37
Clear Creek, No. 47	34 16	118 10	3,200	1.34	3.39	3.61	3.20	10.61	.22	1.87	2	5.59
Coast, No. 48	33 35	117 53	50	.30	1.12	1.18	1.16	1.83				8.80
Corona ¹	33 52	117 35	850	.15	1.35	1.35	1.05	4.30	.60			11.10
Covina	34 05	117 52	575	1.36	1.48	1.86	5.13	1.27				13.38
Crag's Country Club	34 06	118 44	575	(²)	2.75	2.90	6.25	1.48				10.08
Culver City ¹	34 01	118 23	80	.17	1.56	2.25	2.82	3.14	.14			12.17
Curson Canyon, No. 137B	34 07	118 21	1,125	1.48	2.05	1.94	6.25	.45				16.39
Decker's Ranch ¹	33 49	116 45	5,550	.50	1.74	3.00	3.10	6.73	1.32			13.65
Devil Canyon ¹				.19	2.13	2.40	1.91	6.73	.29			16.70
Devil's Gate Dam	34 13	118 11	1,000	1.31	2.38	2.38	9.55	1.08		1.14	2	16.18
Devore ¹	34 14	117 25	2,500	.38	3.40	3.12	1.68	7.35	.25			8.05
Downey (Jordan)	33 56	118 08	132	1.65	.51	1.47	4.01	.41				5.37
Dry Canyon Reservoir ¹	34 28	118 32	1,507	.05	.67	1.21	1.02	2.31	.11			16.03
Dume Canyon, No. 386B	34 05	118 50	1,500	.75	2.90	4.18	6.00	2.20				25.84
East Pine Flat, No. 283A	34 19	117 51	5,742	1.72	5.05	3.31	12.62	3.14		1.69	2	14.66
Eaton Dam	34 14	118 05		1.46	2.83	2.40	7.35	.62				16.25
Echo Mountain ¹	34 13	118 07	3,219	1.78	1.80	2.80	(²)	9.39	.48			10.24
Elizabeth Lake	34 40	118 25	3,400	0.80	1.79	1.22	5.41	.90	.12			11.65
El Monte, No. 108B (city hall)	34 05	118 02	301	(²)	2.65	2.08	6.39	.53				6.69
El Segundo, No. 157E	33 55	118 25	135	1.11	.65	1.23	3.16	.54				9.63
Elsinore ¹	33 40	117 20	1,272	2.18	.32	1.02	4.04	1.88	.19			9.27
Elsinore (Dr. Baer)				1.00	1.43	1.07	.93	4.41	.43			7.62
El Toro C. C. camp ¹				.28	1.06	1.63	1.46	2.91	.28			9.12
Fairmont (near) ¹	34 42	118 25	3,036		1.65	1.83	1.15	4.00	.49			18.68
Fern S. R. E. Plots (San Dimas X)	34 10	117 44	4,900	1.58	6.06	.62	9.72	.70		.48	2	10.13
Fontana	34 06	117 25	1,325	.68	1.11	1.30	3.62	3.30	.12			10.89
Franklin Reservoir (upper), No. 11	34 08	118 25		1.42	2.14	2.26	4.62	.45				9.14
Fullerton (Orange County) ¹	33 52	117 55		1.47	.85	1.39	2.21	2.60	.62			8.35
Gage Canal Headgate ¹				.16	1.62	1.00	.92	3.95	.70			9.47
Girard	34 10	118 36	892	.40	1.16	2.01	5.33	.48	.09			11.45
Glendale, No. 216	34 10	118 15	620	2.34	2.45	2.45	4.00	.21				14.34
Glendale (Lytle) ¹	34 09	118 16	526	.85	2.78	2.50	3.35	4.87	.29			14.00
Glendale (Opid), No. 404	34 10	118 14	653	1.39	3.64	1.90	3.15	3.84	.08			15.33
Glendora, No. 73	34 09	117 50	950	2.59	1.48	2.44	8.17	.52	.13			8.69
Griffith Park Nursery, No. 257	34 07	118 17	750	(²)	2.20	2.00	2.60	1.89				19.40
Haines Canyon (upper)	34 16	118 15	3,450	1.57	3.31	2.95	10.39	1.16	.02			15.00
Haines Canyon (lower)	34 16	118 16	2,250	1.27	2.70	2.36	7.80	.85	.02			6.17
Hamilton Bowl (Southwest Sig Hill)	33 48	118 10	25	1.10	.36	1.14	3.15	.42				6.03
Harkle Road, No. 54 (Orange County) ¹	33 41	117 48	100	.12	1.18	1.19	1.06	2.47	.01			19.26
Henninger Flat	34 12	118 05	2,600	1.30	4.03	3.15	9.50	1.28				22.37
Headlee's Camp, No. 61	34 18	117 50	4,650	1.55	4.17	3.35	12.76	.44	.10			13.85
Headwork's Power Plant, No. 272, Burbank	34 09	118 18	473	1.44	2.09	2.46	7.31	.55				5.28
H. C. Citrus Station (Riverside County) ¹				.21	.52	1.10	.71	2.56	.18			5.50
Hemet (Riverside County) ¹	33 45	116 57	1,700	.65	.22	1.65	.78	2.07	.13			8.94
Hemet Lake Dam (Riverside County) ¹			5,000	(²)	.68	1.55	.82	5.38	.51			30.08
Hoegess Camp	34 12	118 02	2,750	1.71	7.82	4.06	13.95	2.54		1.58	2	6.43
Home, No. 61 (Orange County) ¹	33 43	117 47	130	.30	1.15	1.18	1.30	2.45	.05			12.05
Hurley Flat ¹	33 52	116 47	3,600	.29	2.00	1.80	.74	6.26	.96			12.12
Idlewild (Riverside County)			5,300	(²)	1.36	2.07	1.42	5.73	1.54			8.48
Irvine, No. 55 (Orange County) ¹	33 40	117 45	200	.32	1.45	1.54	1.35	4.23	.07			8.03
Irvine, No. 125 (Orange County) ¹	33 39	117 43	197	(²)	1.06	1.30	1.26	(²)	4.02			9.00
Johnson, No. 56 (Orange County) ¹	34 13	118 39	950	.32	1.06	1.90	1.87	3.85				9.48
Johnson Ranch, No. 22, Canoga Park	34 13	118 39	950	.75	1.26	1.52	5.41	.54				32.20
Kellys Kamp	34 14	117 36	8,300	1.80	3.05	4.00	17.55	4.90	.90			18.35
La Crescenta	34 14	118 14	2,264	1.18	3.76	3.05	9.42	.94				18.80
La Crescenta, No. 251	34 14	118 14	1,565	1.21	3.35	3.08	10.27	.89				

¹ Precipitation measured near sunrise.² Included in next following measurement.

TABLE 1.—Precipitation data (inches and hundredths), Feb. 27 to Mar. 4, 1938, inclusive, for Ventura, Los Angeles, Orange, San Bernardino, and Riverside Counties—Continued

[Precipitation for 24 hours ending near sunset unless otherwise indicated]

Station	Latitude	Longitude	Elevation above m. s. l.	February		March				Greatest		Storm total
				27	28	1	2	3	4	1 hour	Date	
Laguna Beach	33 32	117 46	205	.08	.01	1.44	2.32	1.06	.01			6.42
Lake Arrowhead ¹	34 15	117 12	5,000	.35	7.40	4.33	3.40	14.51	.50	(2 hrs.) 3.80	2	30.49
Lambert, No. 57 (Orange County) ¹	33 42	117 43	400	.30	1.12	1.65	1.35	3.65	.47			8.54
Leecheza Patrol Station, No. 352	34 05	118 53	1,530	.60	2.42	2.85	5.84	1.25	.08			13.04
Leffingwell Ranch, No. 266 (East Whittier) ¹	33 56	118 00	253	(9)	1.96	1.98	2.53	3.03	.26			9.75
Limestone, No. 74	33 46	117 43	1,000	.31	1.27	1.81	1.43	4.75	.11			9.08
Lytle Creek P. H. (Southern California Edison Co.)	34 12	117 27	2,225	1.75	4.10	2.45	9.10	2.55	.53			20.48
Lytle Creek (Base Line St.) ¹	34 08	117 20		.30	1.00	1.72	1.60	5.04	1.26			11.52
Live Oak (Sycamore Canyon) ¹	34 07	117 45	1,530	.97	1.84	1.85	5.51	1.68	T			11.85
Llano	33 40	117 47	3,400	1.27	.47	.58	1.75	.45				4.52
Long Beach ¹	33 46	118 12	70	.02	1.38	1.63	.58	3.30	.47			7.38
Los Angeles	34 03	118 15	417	1.47	2.85	.48	5.88	.38		.90	2	11.06
Los Angeles (Municipal Airport) ¹	33 56	118 23	97	.30	1.15	1.71	2.03	1.96	.11			7.26
Malibu headquarters	34 05	118 36	747	1.27	3.08	3.08	7.98	.35	.03			15.74
Mill Creek, No. 3 (Southern California Edison Co.) ¹	34 05	117 03	2,950	1.16	.92	1.31	3.57	3.40	.56			10.92
Monrovia Canyon ¹	34 10	118 00	975	.26	3.47	3.81	(9)	(9)	5.65			13.19
Monrovia Falls, No. 150	34 11	117 59	1,450	1.20	4.74	3.24	(9)	8.00				17.15
Morro, No. 49 (Orange County) ¹	33 34	117 40	100	.60	1.62	1.12	1.58	2.65				7.42
Mount Wilson	34 13	118 04	5,850	2.16	5.98	3.99	11.83	2.32		1.82	2	26.23
Mouth of Loper Canyon, No. 421 (Fillmore Station)	34 17	118 24	1,173	T	1.41	2.41	1.80	2.96	.41			8.99
Mouth of San Antonio Canyon	34 10	117 40	2,500	.98	3.34	2.35	(9)	10.17				16.84
Newark (San Bernardino, 42d St. at reservoir) ¹	34 44	118 34	3,905	1.17	1.87	1.93	1.65	6.02	.81			12.57
Neenach (Lake Tweedy)	34 23	118 32	1,245	1.05	1.40	1.85	4.78	.25	.10			8.75
Newhall	33 36	117 54	8	.40	.95	1.39	5.22	.94				10.46
Newport Beach ¹	34 10	118 24	650	1.40	1.30	1.83	1.23	1.98				5.95
North Hollywood	34 12	118 23	732	.50	1.52	1.92	5.32	.28				10.13
North Hollywood, No. 222	33 56	118 05		1.36	.62	1.58	4.22	.82	.02			8.28
Norwalk	34 15	118 11	2,000	1.60	3.14	1.91	(9)	12.50				19.15
Oake Wilde, No. 48	34 12	117 41	991	.98	3.34	2.35	(9)	10.17				16.84
Ontario (Power House)	34 29	119 12	900	.28	.73	1.93	7.90	.72				11.36
Ojai	34 15	118 06	4,254	1.79	4.89	3.21	14.92	2.44	.02	1.82	2	27.27
Opid's Camp	34 12	119 11	51	.70	1.89	3.30	1.66	.01				7.56
Oxnard	34 15	118 24	955	.96	1.44	1.58	4.97	.76				9.71
Pacoima, No. 219A (Forestry Warehouse)	34 20	118 24	1,700	.88	1.94	2.01	5.38	1.27				11.48
Pacoima Dam	34 34	118 07	2,654		1.41	.87	.76	2.39	.14			5.57
Palmdale ¹	33 50	116 34	584	.49	.10	.70	.58	4.00	.09			8.96
Palm Springs (Riverside County) ¹	33 48	118 22	450	(9)	2.10	1.52	2.00	1.10				6.72
Palos Verdes, No. 436	34 09	118 08	865	1.72	2.53	2.18	7.70	.68				14.81
Pasadena	34 09	118 00	852	.44	3.53	2.70	3.64	4.59	.05			14.95
Pasadena, No. 413 (Central Fire House)	33 48	117 14	1,466	1.00	.55	1.15	1.10	2.63	.12			6.55
Perris (Riverside County) ¹	33 47	117 46	550	.31	1.30	1.23	1.35	2.18	.09			6.46
Peter's, No. 72 (Orange County) ¹	34 15	118 13	4,250	1.43	3.60	3.14	8.12	1.06		1.12	2	17.35
Picken's Canyon	34 24	118 44	675	(9)	1.33	1.53	5.39	.93	.05			9.23
Piru, No. 593 (Newhall Ranch)	34 03	117 45	870	.12	1.45	2.11	2.17	4.21				10.06
Pomona ¹	34 04	117 45	857	.10	1.55	1.87	2.45	3.52	.24			9.73
Pomona, No. 256, Southern Pacific Ry. ¹	34 35	118 27	2,100	.95	1.64	1.50	3.82	.31				8.22
Power House, No. 1 (L. A. C. P. & L.) ¹	34 32	118 31	1,580	T	.87	1.78	1.62	3.63	.18			8.08
Power House, No. 2 (L. A. C. P. & L.) ¹	34 19	118 30	1,248	T	1.22	3.21	1.97	3.62	.21			10.23
Power House, No. 3 (L. A. C. P. & L.) ¹	34 06	117 48	1,030	1.09	1.64	1.68	5.45	1.15				11.01
Puddingstone Dam, No. 90	34 00	117 56	496	.25	2.00	2.05	2.85	2.95	.14			10.24
Puente, No. 254	34 36	118 33	2,041	.44	1.79	1.79	8.30	.80				13.12
Radium Hot Springs	34 03	116 50	7,200	.50	4.00	3.50	1.85	13.50	.85			24.23
Raywood Flat ¹	34 04	117 12	1,360	1.10	.44	1.05	1.66	3.08	.38			9.71
Redlands ¹	33 58	117 26	865	.12	.93	.90	1.72	1.46	.07			5.26
Riverside	34 14	118 22	1,000	.15	1.71	1.91	1.37	3.33	.04			8.51
Roscoe, No. 14 ¹				1.13	2.14	2.07	6.83	.77	.06			13.13
Rossmyrne Fire Area (Glendale)	34 07	117 16	1,172	1.36	1.10	1.34	4.46	1.56				9.82
San Bernardino (near)	33 38	117 53	40	.37	.90	1.04	1.14	2.02	T			5.47
Salt Works X (Orange County) ¹	34 07	117 18	1,048	.41	1.67	1.38	1.04	4.84	.56			9.90
San Bernardino (2d and D Sts.) ¹	34 44	118 43	4,250	(9)	1.65	1.59	(9)	4.33				7.57
Sandberg	34 06	117 48	960	1.12	1.67	1.90	6.20	1.04				11.93
San Dimas	34 09	117 46	1,350	1.14	2.22	2.90	7.18	1.24				14.08
San Dimas Dam, No. 80 ¹	34 17	118 27	900	.03	1.31	2.64	1.86	3.03	.06			8.93
San Fernando ¹	34 17	118 29	1,150	1.30	2.65	2.10	3.25	.07				9.37
San Fernando Reservoir, No. 293 (lower)	34 13	117 51	1,600	1.43	3.75	3.12	12.52	1.17				21.90
San Gabriel Camp, No. 1, No. 76	34 14	117 49	1,500	1.48	3.36	2.88	10.90	1.60	.03			20.25
San Gabriel Canyon, No. 379 (east fork)	34 13	117 51	1,251	.15	2.83	5.30	1.92	8.16	.13			18.49
San Gabriel Dam, No. 1 ¹	34 15	117 58	2,335	1.90	4.53	3.52	13.42	1.18		1.61	2	24.55
San Gabriel Dam, No. 2, No. 334	34 13	117 51	1,600	1.36	3.67	3.07	12.19	1.55				21.64
San Gabriel Dam RS, No. 76	34 12	117 45		1.34	4.48	.78	8.82					14.85
San Gabriel Divide (San Dimas X)	34 09	117 54	850	1.37	2.80	2.60	6.47	1.61				8.93
San Gabriel Power House	33 47	116 57	1,550	.85	.32	1.28	2.15	1.15	.19			5.10
San Jacinto	33 43	118 17	90	.09	.85	1.53	.90	1.28	.45			7.86
San Pedro ¹	33 31	117 40	103	.30	1.13	1.77	1.43	3.03	.30			9.49
San Juan Capistrano (Orange County) ¹	33 46	117 51	133	1.38	.84	1.03	2.90	3.36	.08			6.51
Santa Ana ¹	33 45	117 52	130	.37	1.31	1.38	1.43	2.00	.02			9.92
Santa Ana (Orange County) ¹				1.05	1.56	1.27	3.10	Gauge washed away.				16.38
Santa Ana No. 1 (Intake) Southern California Edison Co.) ¹	34 02	117 06	2,000	1.38	.84	1.03	2.90	3.26	.51			29.00
Santa Ana, No. 3 (Southern California Edison Co.) ¹	34 11	118 01	1,400	1.30	4.06	3.53	6.76	.73				9.22
Santa Anita Dam, No. 63A ¹	34 12	118 01	1,703	.47	7.12	7.41	(9)	14.00				8.47
Santa Anita Ranger Station	34 02	118 28	140	.80	1.90	1.56	4.11	.85				20.65
Santa Monica	34 21	119 04			.88	2.10	3.24	2.25				9.49
Santa Paula ¹				2.50	3.50	1.50	12.15	.75	.25			6.38
San Geronimo (Nevada, Calif. plant)	33 48	117 44	600	.32	1.47	1.75	1.47	4.43	.05			
Santiago, No. 102 (Orange County) ¹	34 25	118 34	1,093	.58	.77	1.05	3.27	.55	.16			
Saugus, No. 200 (substation Southern California Edison Co.)												

¹ Precipitation measured near sunrise.² Included in next following measurement.³ Precipitation midnight to midnight.

TABLE 1.—Precipitation data (inches and hundredths), Feb. 27 to Mar. 4, 1938, inclusive, for Ventura, Los Angeles, Orange, San Bernardino, and Riverside Counties—Continued

[Precipitation for 24 hours ending near sunset unless otherwise indicated]

Station	Latitude	Longitude	Elevation above m. s. l.	February		March				Greatest		Storm total
				27	28	1	2	3	4	1 hour	Date	
Saw Pit Dam, No. 68	34 10	117 59	1,150	1.05	3.81	2.91	7.51	4.33				19.61
Seven Oaks	34 10	116 55	5,000	1.42	.98	2.10	8.47	4.69	.66			18.22
Sepulveda, No. 91	34 14	118 28	815	.39	1.22	2.33	1.71	3.17				8.82
Shady, No. 51 (Orange County) ¹	33 38	117 48	300	.48	1.20	1.72	1.25	2.90	.08			7.72
Sierra (Southern California Edison Co.)				1.25	4.51	3.45						
Sierra Madre	34 12	118 01	1,050	1.54	4.18	2.18	7.89	.68				16.37
Sierra Madre Dam, No. 144	34 11	118 02	1,400	.66	3.54	2.69	9.18	1.03				17.00
Sleepy Hollow (Colby Ranch)	34 18	118 07	2,950	2.13	1.70	2.45	10.95	1.52		1.33	2	18.8
Snow Creek ¹	33 53	116 41	1,300	(?)	1.50	(?)	(?)	(?)	11.00			12.50
Soledad, No. 409 (Mitchell)	34 25	118 26	1,472	.85	1.61	1.40	4.60	.40	.10			8.96
Squirrel Inn	34 15	117 13	5,700	2.15	5.10	3.15	10.97	4.70				26.17
Sturtevant's Camp, No. 58	34 13	118 02	3,375	2.00	6.07	2.98	12.12	1.96	.10			25.13
Summit Topango	34 08	118 36	1,520	(?)	2.70	1.95	(?)	6.02				10.67
Sunset Canyon (Burbank No. 39)	34 12	118 17	1,650	1.29	2.01	2.44	6.78					13.25
Switzerland, No. 52	34 16	118 09	3,000	1.20	2.69	2.02	12.41	1.46				19.78
Sylmar, No. 30	34 19	118 28	1,250	(?)	2.32	1.43	4.35	.68				8.78
Table Mountain	34 23	117 41	7,500	1.80	1.40	.88	4.59	1.71				10.38
Tanbark Flat, No. 155	34 12	117 46	2,700	1.26	3.66	3.25	11.24	1.38	.31			21.10
Tanbark Laboratory (San Dimas X)	34 11	117 46	2,675	1.23	6.34	.73	11.47	.96		.82	2	20.73
Topanga Canyon R. S., No. 6	34 05	118 36	747	1.27	3.03	3.17	6.70	.16		1.00	2	14.33
Torrance, No. 258	33 51	118 19	57	1.32	.45	1.23	3.05	.21				6.26
Tribuca C. C. camp (Orange County) ¹				.25	1.20	2.19	1.70	3.12	.24			8.70
Tujunga	34 15	118 17	1,850	1.01	2.12	2.07	6.02	1.88				13.10
Trustin (near) ¹	33 43	117 48	125	.32	.97	1.54	1.35	4.23				8.41
University of California at Los Angeles	34 04	118 26		.27	2.49	2.66	4.60	1.51	.03			11.56
Upland ¹	34 09	117 39	1,740	.10	1.42	1.98	2.45	5.09	.22			11.26
Valyermo	34 26	117 51	3,800	1.00	.98	1.17	3.28	.32				6.75
Van Nuys ¹	34 11	118 27	695	.17	1.53	2.46	2.24	3.29	.02			9.71
Venice, No. 126	33 59	118 28	7	(?)	2.96	1.38	4.19	.51				9.04
Vicente Point, No. 44	33 44	118 25	125	.78	.39	1.27	2.59	.49				5.52
Ventura	34 20	119 14	50	(?)	1.08	3.74	.82					5.64
Vincent Patrol Station	34 29	118 08	3,250	1.00	.30	.78	3.37	.48				5.93
Victorville (A. S. Amaral) ¹	34 30	117 21	2,713	.21	.73	.68	.17	1.10	.27			3.16
Villabrook No. 70 (Orange County) ¹	33 48	117 50		.40	1.45	1.90	1.95	3.00	.30			9.00
West Fork San Dimas Experiment	34 10	117 47	2,100	1.14	5.34	.82	8.94	1.00		.38	2	17.24
West Los Angeles (Sawtelle City Hall) No. 140	34 03	118 27	232	(?)	3.50	1.77	5.21	.62				11.10
Whittier Narrows No. 220 (Riverside)	34 01	118 04	195	1.16	1.13	1.73	4.75	.61				9.38
Whittier	33 59	118 02	365	1.28	.67	1.65	4.50	.73				8.83
Walnut	34 00	117 52	475	(?)	2.29	1.89	(?)	6.59				10.77
West Pine Flat	34 19	117 50	5,369	1.65	5.02	3.35	12.32	3.34				25.68
Wilmington No. 118B	33 47	118 16	40	1.39	1.49	.15	3.67	.63				7.33
Yorba Linda ¹	33 52	117 48	405	.70	.84	1.77	2.43	3.34	.13			9.21

¹ Precipitation measured near sunrise.² Included in next following measurement.

The accompanying rainfall table lists 224 gaging stations¹ throughout the excessive rainfall areas of the 5 counties affected—Ventura, Los Angeles, San Bernardino, Orange, and Riverside. The table shows the latitude, longitude, and elevation of the stations listed; also the daily rainfall, and the total catch for each of the several stations. Hourly intensities are shown also for stations exceeding an inch per hour or more. It will be noted that the hourly intensities were not phenomenal, generally—the highest analyzed being Clear Creek station with 1.87 inches. It is probable, however, that not over 10 to 15 percent of the stations possessed recording gages. It is interesting to note, that Opids Camp in the San Gabriel Mountains received 10.89 inches in 8 hours on March 2, 1938, and that the following 24-hour amounts, all on March 2, were recorded:

	Inches
Kellys Kamp, San Gabriel Mountains	17.55
Big Bear Lake Dam, San Bernardino Mountains	15.06
Opids Camp, San Gabriel Mountains	14.92
Lake Arrowhead, San Bernardino Mountains	14.51

Deep Creek, mentioned above, one of the main headwater tributaries of the Mojave River, rises in the San Bernardino Mountains between Big Bear Lake and Lake Arrowhead. It was the floodwaters of this stream that caused the Mojave River to flood out through the desert of the same name, resulting in much damage and overflowing from Soda Lake through Baker to Silver Lake for the first time since 1922, filling the latter at its center to a depth of probably 22 feet. Both of these lakes are

usually merely dry beds. So far as known the floodwater caught in Silver Lake in January 1916 was the previous greatest amount, at least back to the sixties. It is with this thought in mind that the following is quoted from page 381 of the Mojave Desert Region of California, U. S. G. S. Water Supply Paper No. 578:

After heavy rains in January 1916 so much water flowed down to the Mojave River that it not only reached Soda Dry Lake, but continued across the Playa to Silver Lake, which filled it to a depth of about 10 feet. It is said that practically all the water in Silver Lake, when the Playa of that name is flooded, comes from Mojave River, particularly the headwater region, and not from the desert land immediately adjacent to the Playa.

As Silver Lake reached a depth of only 10 feet during the 1916 phenomenal flood it is easy to see how much more water passed down the Mojave River during the recent flood to bring a depth of 20 feet or more to the said dry lake bed, and causing much flood damage in the vicinity of Victorville, Barstow, and Baker, including destruction of highways and railway beds.

An attempt has been made to obtain accurate survey data on extent of areas overflowed by the floods in the several streams affected, the amount of damage, and the number of lives lost as a result of the floods. The surveys are incomplete at the present time and may not be completed for several weeks. It is impossible to even approximate the total areas flooded, but they will run into hundreds of square miles. The Los Angeles County agent has made a study of damage in this county alone to agriculture, from which we quote:

Damage from flood waters in orchards	\$130,000
Damage to vegetables and berries	41,000
Damage to tilled crops	97,300

¹ Including, besides the Weather Bureau cooperative stations, gages operated by the Los Angeles and Orange County Flood Control Districts, by the various counties and cities in the region involved, by power companies, by the Forest Service, Soil Conservation Service, and by other agencies, public and private. The operators of the gages are indicated to some extent in the table.

Damage to nursery stock.....	\$30,000
Damage from rain and wind to oranges.....	232,000
Damage from rain and wind to strawberries.....	125,000
Damage from rain and wind to cut flowers.....	35,000
Total.....	690,300

The damage listed above is only a fraction of the entire loss in Los Angeles County alone, when highways, railways, buildings, soil erosion, livestock, poultry, automobiles, farm equipment, power lines, telegraph and telephone lines, etc., are all considered. Extend this loss to the other four counties involved and the loss becomes tremendous. A rough estimate, at the close of the flood period for southern California, was placed at \$24,500,000. It is unlikely that any close approximation of the intangible losses, such as soil erosion can ever be made. It is known

that millions of tons of soil and subsoil were removed by floodwaters from the mountains, valleys, and lowlands; much of the eroded material was deposited over areas to become a burden or a real menace; large portions were actually washed into the ocean; large quantities filled the many storm debris basins and are being removed; untold tons were deposited in the bottoms of southern California artificial lakes and reservoirs.

Data obtained from the American Red Cross show deaths from the great flood as follows:

Los Angeles County.....	29
Orange County.....	20
San Bernardino County.....	11
Riverside County.....	15
Ventura County.....	4
Total.....	79

NOTES AND REVIEWS

Monthly Observed Sunspot Relative Numbers for 1937, by CHARLES M. LENNAHAN.—The sunspot relative numbers for 1937 have recently been published in the *Astronomische Mitteilungen*, Nr. 136, Zurich 1938, by W. Brunner. These numbers are based not only upon observations made at Zurich and Arosa but also upon those made at 55 other stations distributed throughout the world; they therefore differ somewhat from the provisional numbers published regularly in the MONTHLY WEATHER REVIEW.

Sunspot relative numbers for 1937

January.....	132.5	August.....	137.7
February.....	128.5	September.....	100.7
March.....	83.9	October.....	124.9
April.....	109.3	November.....	74.4
May.....	116.7	December.....	88.8
June.....	130.3		
July.....	145.1	Year.....	114.4

No day during the year was free of sunspots.

The same issue of *Astronomische Mitteilungen* gives the mean relative number for 1936 as 79.7 and not 80.4 as incorrectly published in *Astronomische Mitteilungen* No. 135, page 197, and as republished in the MONTHLY WEATHER REVIEW, volume 65: 338, September 1937.

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[RICHMOND T. ZOCH, in Charge of Library]

By AMY D. PUTNAM

RECENT ADDITIONS

The following have been selected from among the titles of books recently received as representing those most likely to be useful to Weather Bureau officials in their meteorological work and studies:

Abbot, C. G.

Further evidence on the dependence of terrestrial temperatures on the variations of solar radiation. Washington. 1936. 4 p. figs. 24½ cm. (Smithsonian miscellaneous collections. Arthur fund.)

Antevs, Ernst.

Rainfall and tree growth in the Great basin . . . Edited by J. K. Wright. [Washington, D. C.] 1938. 97 p. illus. (maps), diagrs. (2 fold. in pocket). 25½ cm. [Carnegie institution of Washington. Publication no. 469.] American geographical society of New York, Special publication no. 21. "List of references." p. [87]-91.

Baldwin, Henry I., & Brooks, Charles F.

Forests and floods in New Hampshire. Boston, Mass. 1936. 28 l. tables, maps. 28 cm. Mimeographed. (New England regional planning commission. Publication. no. 47. December 1936.)

Barth, Richard.

Das Wetter der Heimat: Ein didaktischer Aufbau. Erfurt. 1935. 111 p. illus., tables, diagrs. 23 cm. Title facing titlepage: Volkhafte Schularbeit. Beiträge zur deutschen Erziehung. A. Hoffmann, W. Kramer, & R. Vogel.

Benedik, Nikolaus.

Systematische Wettervorhersagen. Betrachtungen über die Periodizität des Wetters. Wien. 1933. 63 p. tables, diagrs. 18 cm.

Berlage, H. P., Jr.

Metingen van de intensiteit van de zonnestraling op verschillende plaatsen in Ned.-Indië in de laatste jaren. Batavia.

1936. p. [104]-116. figs., tables. 24½ cm. [Overdruk uit het verslag van de 15e vereeniging van proefstationpersoneel te Batavia, October 1935, pagina 104-116.]

Brunt, D.

Climatic cycles. London & Beccles. 1937. p. [214]-238. figs., tables. 24½ cm. [Reprinted from the Geographical journal, v. 89, no. 3, March 1937.]

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Chapman, S.

The earth's magnetism. London. 1936. 116 p. diagrs. 17½ cm.

Diaz, Severo.

Mis ensayos en la previsión del tiempo. 1895-1935. Guadalajara, Jal. 1936. 29 p. fig., diagr. 22½ cm.

Jatho, Alfred.

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Periodical of the Hydro-meteorological committee of the USSR People's commissary of agriculture and of the Science section of the RSFSR People's commissary of education. Moscow. 1931- . 25½ cm. (In Russian.) v. 1, no. 1-2, 1931. v. 2, no. 1-3, 1932.

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SOLAR OBSERVATIONS

[Meteorological Research Division, EDGAR W. WOOLARD in charge]

SOLAR RADIATION OBSERVATIONS, APRIL 1938

By CHARLES M. LENNAHAN

Measurements of solar radiant energy received at the surface of the earth are made at eight stations maintained by the Weather Bureau, and at nine cooperating stations maintained by other institutions. The intensity of the total radiation from sun and sky on a horizontal surface is continuously recorded (from sunrise to sunset) at all these stations by self-registering instruments; pyrheliometric measurements of the intensity of direct solar radiation at normal incidence are made at frequent intervals on clear days at three Weather Bureau stations (Washington, D. C., Madison, Wis., Lincoln, Nebr.) and at the Blue Hill Observatory of Harvard University. Occasional observations of sky polarization are taken at the Weather Bureau stations at Washington and Madison.

The geographic coordinates of the stations, and descriptions of the instrumental equipment, station exposures, and methods of observation, together with summaries of the data obtained up to the end of 1936, will be found in the MONTHLY WEATHER REVIEW, December 1937, pp. 415 to 441; further descriptions of instruments and methods are given in Weather Bureau Circular Q.

Table 1 contains the measurements of the intensity of direct solar radiation at normal incidence, with means and their departures from normal (means based on less than 3 values are in parenthesis). At Madison and Lincoln the observations are made with the Marvin pyrheliometer; at Washington and Blue Hill they are obtained with a recording thermopile, checked by observations with a Marvin pyrheliometer at Washington and with a Smithsonian silver disk pyrheliometer at Blue Hill. The table also gives vapor pressures at 8 a. m. (75th meridian time) and at noon (local mean solar time).

During May 1938 direct solar radiation intensities averaged about normal at Washington, D. C., and above normal at Madison, Lincoln, and Blue Hill. The radiation received at Lincoln on the 14th and 27th was greatly depleted due to dust in the air; and also on the 28th because of smoke.

Table 2 contains the average amounts of radiation received daily on a horizontal surface from both sun and sky during each week, their departures from normal and the accumulated departures since the beginning of the year. The values at most of the stations are obtained from the records of the Eppley pyrheliometer recording on either a microammeter or a potentiometer.

Chicago, New York, Fairbanks, New Orleans, San Juan, and Friday Harbor received an excess of total solar and sky radiation during May 1938. Ten of the other stations for which normals exist received a deficiency of radiation during the month.

Polarization measurements were made on 7 days at Madison giving a mean value of 51.4 percent and a maximum of 53.5 percent on the 10th; both of these values are below the corresponding normals for the month.

TABLE 1.—Solar radiation intensities during May 1938

[Gram-calories per minute per square centimeter of normal surface]

WASHINGTON, D. C.												
Date	Sun's zenith distance										Local mean solar time	
	8 a.m.	78.7°	75.7°	70.7°	60.0°	0.0°	60.0°	70.7°	75.7°	78.7°		Noon
	75th mer. time	Air mass										
		A. M.					P. M.					
		e	5.0	4.0	3.0	2.0	*1.0	2.0	3.0	4.0		5.0	e
May 2.....	mm.	6.76	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	mm.	
May 3.....		8.48				1.17					5.79	
May 5.....		11.81					1.18				7.57	
May 6.....		13.13	0.54	0.63	0.73	.94	1.32				13.13	
May 12.....		4.37				.75	1.38	0.97	0.68		7.57	
May 31.....		6.02					1.43	1.24			3.99	
Means.....		(.54)	(.63)	(.73)	.95	1.33	(1.10)	(.68)			4.75	
Departures.....		-.09	-.09	-.11	-.06	+.05	+.16	-.11				

MADISON, WIS.

May 6.....	4.57				1.26	1.44	1.25				4.75
May 10.....	6.76		0.97	1.11	1.28	1.51					7.87
May 11.....	4.75		1.02	1.16	1.32	1.51					4.37
May 12.....	3.81		.81	1.00	1.30	1.50					4.95
May 13.....	3.63		.98	1.10	1.22						3.99
May 16.....	6.76		.98	1.11	1.28	1.49					6.50
May 24.....	5.79		1.04	1.18	1.32	1.52					5.56
Means.....		.97	1.11	1.28	1.50	(1.25)					
Departures.....		+.13	+.10	+.16	+.12	+.20					

LINCOLN, NEBR.

May 2.....	13.61					1.39					10.97
May 3.....	15.65					1.39	1.06				10.59
May 5.....	6.50					1.24	1.49				7.29
May 8.....	4.37	0.83	0.96	1.12	1.31	1.54					4.57
May 9.....	5.79	.87	.98	1.11	1.31	1.51	1.29	1.10	0.98	.86	5.79
May 10.....	6.02		.86	.95	1.23	1.49		.92			7.04
May 11.....	9.83			1.06							9.83
May 13.....	6.50	.68	.77	.86	1.14						8.48
May 14.....	5.56					.86					4.37
May 22.....	7.29		.82	.91			1.49	1.27			8.48
May 23.....	9.47										5.36
May 27.....	10.97	.36	.49	.67							9.47
May 28.....	9.14		.54	.65							13.13
Means.....		.68	.77	.92	1.25	1.40	1.21	(1.01)	(.98)	(.86)	
Departures.....		+.63	-.01	.00	+.14	+.02	+.10	+.10	+.17	+.18	

BLUE HILL, MASS.

May 21.....	9.2				1.48	1.24	1.17				8.8
May 22.....	9.9				1.19	.96	0.79				9.9
May 30.....	5.4			1.06	1.24	1.48	1.08	.93			5.0
May 31.....	5.6				1.26	1.47	1.07	.89			5.2
Means.....				(1.06)	(1.25)	1.48	1.19	1.02	(.86)		
Departures.....				-.02	+.12	+.11	+.09	+.10	+.05		

*Extrapolated.

TABLE 2.—Average daily totals of solar radiation (direct+diffuse) received on a horizontal surface

Week beginning—	Gram-calories per square centimeter																	
	Wash- ington	Mad- ison	Lin- coln	Chica- go	New York	Fresno	Fair- banks	Twin Falls	La Jolla	Miami	New Orleans	River- side	Blue Hill	San Juan	Friday Harbor	Ithaca	New- port	
	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	
Apr. 30	488	542	394	550	446	551	472	438	587	560	392	489	533	494	514	432	605	
May 7	416	456	468	468	391	678	450	590	593	468	417	618	398	690	490	214	478	
May 14	288	303	369	281	325	612	463	474	331	529	458	310	446	600	698	351	495	
May 21	345	497	538	418	403	713	497	666	529	478	497	646	415	704	712	425	458	
May 28	439	452	536	518	598	714	432	733	523	363	530	606	616	663	644	600	682	
Departures of daily totals from normals																		
	+21	+101	-77	+166	+40	-74	+70	-75	+16	+63	-3	-63	+30	-57	-50	+72	-----	
Apr. 30	-37	+8	+19	+68	-1	+27	-1	+2	+23	-53	+20	+62	-93	+154	-49	-198	-----	
May 7	-175	-173	-147	-141	-86	-57	-4	-134	-177	+36	+52	-207	-49	+112	+143	-66	-----	
May 14	-155	+5	-16	-34	-45	+37	+43	+19	+58	-23	+76	+111	-138	+153	+138	-107	-----	
May 21	-91	-45	+15	+49	+131	+27	+13	+141	-11	-103	+29	+53	+50	+95	+89	+83	-----	
May 28																	-----	
Accumulated departures since Jan 1																		
	-8,733	-4,081	-2,534	+2,044	+763	-2,954	+3,199	-4,727	-770	-1,281	+3,913	-1,897	-1,344	+6,949	+6,923	+2,135	-----	

POSITIONS AND AREAS OF SUN SPOTS

[Communicated by Capt. J. F. Hellweg, U. S. Navy (Ret.), Superintendent, U. S. Naval Observatory. Data furnished by the U. S. Naval Observatory in cooperation with Harvard and Mount Wilson Observatories. The difference in longitude is measured from the central meridian, positive west. The north latitude is positive. Areas are corrected for foreshortening and are expressed in millionths of the sun's visible hemisphere. The total area for each day includes spots and groups]

Date	East- ern stand- ard time	Mt. Wilson group No.	Heliographic			Area		Spot count	Observatory
			Diff. in longi- tude	Longi- tude	Lat- tude	Spot or group	Total for each day		
1938	A. M.		°	°	°				
May 1	11 29	5872	-40.0	263.9	-22.0	194	-----	5	U. S. Naval.
		5871	-35.0	268.9	+25.0	170	-----	3	
		5870	-31.0	272.9	-30.0	48	-----	3	
		5868	-24.0	279.9	-21.0	48	-----	13	
		5869	-21.0	282.9	+23.0	339	-----	8	
		(*)	-20.0	283.9	+12.0	48	-----	3	
		5867	-19.5	284.4	-29.0	485	-----	5	
		5873	-19.0	284.9	-20.0	97	-----	1	
		5865	+27.5	331.4	-19.5	61	-----	1	
		5862	+40.0	343.9	+9.0	194	-----	3	
		5864	+42.5	346.4	+12.0	315	1,999	9	
May 2	11 24	5874	-74.0	216.7	-3.5	194	-----	3	Do.
		5872	-25.0	265.7	-22.0	170	-----	6	
		5871	-21.0	269.7	+25.0	170	-----	4	
		5868	-13.0	277.7	-22.0	145	-----	15	
		5869	-8.5	282.2	+23.0	291	-----	12	
		5873	-7.0	283.7	-20.0	73	-----	1	
		(*)	-7.0	283.7	+11.0	48	-----	3	
		5867	-6.0	284.7	-29.0	339	-----	6	
		5865	+40.5	331.2	-19.5	61	-----	1	
		5862	+54.0	344.7	+9.0	194	-----	1	
		5864	+56.0	346.7	+12.0	388	2,073	8	
May 3	11 20	5874	-60.0	217.5	-3.5	97	-----	4	Do.
		5872	-12.0	265.5	-23.0	170	-----	4	
		5871	-9.0	268.5	+25.0	291	-----	8	
		5868	-3.0	274.5	-22.0	485	-----	40	
		5869	+7.0	284.5	+23.0	218	-----	6	
		5873	+7.0	284.5	-20.0	73	-----	3	
		5867	+7.0	284.5	-29.0	339	-----	10	
		(*)	+8.0	285.5	+11.0	12	-----	3	
		5865	+53.0	330.5	-20.0	48	-----	3	
		5862	+68.0	345.5	+9.0	194	-----	3	
		5864	+70.0	347.5	+12.0	145	2,072	4	
May 4	10 51	5877	-77.0	187.6	-8.0	388	-----	8	Do.
		5874	-47.5	217.1	-4.0	97	-----	7	
		5876	-29.5	235.1	-38.0	218	-----	24	
		5872	0.0	264.6	-23.0	121	-----	4	
		5871	+3.0	267.6	+25.0	194	-----	10	
		5868	+11.0	275.6	-22.0	436	-----	48	
		5869	+19.0	283.6	+23.0	194	-----	4	
		5867	+19.0	283.6	-29.0	339	-----	8	
		5873	+21.0	285.6	-20.0	61	-----	3	
		5865	+67.0	331.6	-19.5	36	-----	2	
		5875	+67.0	331.6	+20.0	48	-----	8	
		5862	+82.0	346.6	+9.0	194	-----	2	
		5864	+85.0	349.6	+12.0	97	2,423	3	
May 5	11 8	5878	-81.0	170.2	+23.5	194	-----	2	Do.
		5877	-64.0	187.2	-8.0	485	-----	30	
		5874	-33.0	218.2	-4.5	61	-----	4	
		5876	-16.0	235.3	-37.0	242	-----	20	
		5872	+13.0	264.2	-23.0	97	-----	3	
		5871	+18.0	269.2	+25.0	145	-----	7	

See footnotes at end of table.

POSITIONS AND AREAS OF SUN SPOTS—Continued

Date	East- ern stand- ard time	Mt. Wilson group No.	Heliographic			Area		Spot count	Observatory
			Diff. in longi- tude	Longi- tude	Lat- tude	Spot or group	Total for each day		
1938	A. M.		°	°	°				
May 5	11 8	5868	+25.0	270.2	-22.0	412	-----	22	U. S. Naval.
		5869	+32.0	283.2	+23.0	194	-----	2	
		5867	+32.0	283.2	-30.0	339	-----	14	
		5873	+35.0	286.2	-20.0	61	-----	8	
		5865	+80.0	331.2	-19.0	12	-----	1	
		5875	+80.0	331.2	+21.0	12	2,254	1	
May 6	11 17	5878	-67.5	170.4	+23.5	97	-----	1	Do.
		5877	-50.5	187.4	-8.0	533	-----	20	
		5874	-20.0	217.9	-4.5	48	-----	2	
		5876	-4.0	233.9	-37.0	291	-----	30	
		5872	+26.0	263.9	-23.0	97	-----	3	
		5871	+31.0	268.9	+25.0	121	-----	3	
		5868	+37.0	274.9	-22.0	342	-----	10	
		5869	+45.0	282.9	+23.0	194	-----	2	
		5867	+46.0	283.9	-30.0	291	-----	5	
		5873	+49.0	286.9	-20.0	48	-----	2	
May 7	10 59	5883	-88.0	139.8	-25.0	194	1,962	2	Do.
		5881	-72.0	152.8	+25.0	121	-----	5	
		5878	-53.0	171.8	+24.0	73	-----	2	
		5877	-37.0	187.8	-8.0	776	-----	20	
		5880	-19.0	205.8	+23.0	48	-----	5	
		5874	-7.0	217.8	-5.0	36	-----	3	
		5876	+9.0	233.8	-37.0	339	-----	22	
		5872	+39.0	293.8	-23.0	97	-----	4	
		5871	+45.0	299.8	+25.0	97	-----	4	
		5868	+50.0	274.8	-22.5	145	-----	8	
		5869	+58.0	282.8	+24.0	194	-----	2	
		5867	+59.5	284.3	-30.0	242	-----	4	
		5873	+60.5	285.3	-20.0	48	-----	1	
		5879	+78.0	302.8	-9.0	12	2,422	4	
May 8	10 53	5883	-75.0	130.7	-24.0	212	-----	4	Mt. Wilson.
		5881	-57.0	154.7	+24.0	194	-----	7	
		5878	-39.0	172.7	+24.0	97	-----	1	
		5884	-30.0	181.7	+18.0	73	-----	5	
		5877	-24.0	187.7	-7.0	970	-----	15	
		5880	-7.0	204.7	+24.0	73	-----	6	
		5874	+7.0	218.7	-5.0	24	-----	1	
		5876	+22.0	233.7	-37.0	339	-----	26	
		5872	+50.5	262.2	-23.0	61	-----	1	
		5871	+60.0	271.7	+25.0	97	-----	3	
		5868	+63.0	274.7	-23.0	145	-----	3	
		5869	+70.0	281.7	+24.0	242	-----	1	
		5867	+71.0	282.7	-30.0	242	-----	3	
		5873	+74.0	285.7	-20.0	48	2,847	1	
May 9	11 8	5887	-78.0	120.3	-19.0	97	-----	6	U. S. Naval.
		5886	-77.0	121.3	+17.0	97	-----	6	
		5883	-60.0	138.3	-25.0	291	-----	12	
		5885	-43.0	155.3	-13.0	12	-----	3	
		5881	-42.0	156.3	+25.0	291	-----	13	
		5878	-26.0	172.3	+24.0	97	-----	2	
		5884	-16.0	182.3	+18.5	73	-----	23	
		5877	-11.0	187.3	-7.0	1,018	-----	35	
		5880	+7.0	205.3	+25.0	73	-----	14	
		5876	+36.0	234.3	-37.0	242	-----	12	
		5872	+65.0	263.3	-22.0	73	-----	2	
		5871	+72.0	270.3	+25.0	48	-----	1	
		5868	+80.0	278.3	-21.0	73	-----	1	
		5867	+86.0	284.3	-29.0	291	-----	2	
		5869	+89.0	287.3	+24.0	145	2,921	1	

POSITIONS AND AREAS OF SUN SPOTS—Continued

POSITIONS AND AREAS OF SUN SPOTS—Continued

Date	East- ern stand- ard time	Mt. Wilson group No.	Heliographic Diff. in longi- tude	Longi- tude	Latitu- de	Spot or group	Total for each day	Spot count	Observatory
1938									
May 10...	h. m.								
	14 24	5888	-84.0	99.3	-11.5	582		4	U. S. Naval.
		5887	-63.0	120.3	-20.0	121		7	
		5886	-59.0	124.3	+17.0	121		6	
		5883	-46.0	137.3	-25.0	242		3	
		5881	-28.0	155.3	+26.0	291		22	
		5878	-11.0	172.3	+25.0	73		5	
		5884	-1.0	183.3	+18.0	97		13	
		5877	+5.0	188.3	-7.0	921		25	
		5880	+25.0	208.3	+23.0	121		14	
		(*)	+38.5	221.8	-9.0	6		2	
		5876	+54.0	237.3	-36.0	121		5	
		5872	+81.0	264.3	-21.0	48	2,744	2	
May 11...	13 25	5889	-88.0	82.6	-10.0	97		2	Do.
		5888	-74.0	96.6	-11.5	776		5	
		5887	-51.0	119.6	-20.5	61		7	
		5886	-47.0	123.6	+17.0	97		6	
		5883	-33.0	137.6	-25.0	242		1	
		5881	-15.0	155.6	+24.5	582		18	
		5878	+1.0	171.6	+25.0	61		3	
		5880	+12.0	182.6	+18.0	97		8	
		5877	+18.0	188.6	-7.0	970		19	
		5876	+37.0	207.6	+23.0	194		6	
		5875	+70.0	240.6	-34.0	170	3,347	2	
May 12...	11 4	5889	-74.0	84.7	-10.0	242		4	Do.
		5888	-60.0	98.7	-11.5	582		9	
		5887	-39.0	118.7	-20.0	73		5	
		5886	-33.0	125.7	+17.0	73		3	
		5883	-22.0	136.7	-24.0	242		2	
		5881	-3.0	155.7	+25.0	582		15	
		5878	+12.0	170.7	+25.0	48		2	
		5884	+25.0	183.7	+18.0	48		6	
		5877	+30.0	188.7	-7.0	873		14	
		5880	+46.0	204.7	+23.0	85	2,848	6	
May 13...	11 24	5890	-88.0	57.3	-14.0	291		1	Do.
		5889	-60.0	85.3	-10.0	291		4	
		5888	-45.0	100.3	-11.5	582		8	
		5887	-26.0	119.3	-20.0	48		4	
		5886	-19.5	125.8	+17.0	194		8	
		5883	-9.5	135.8	-24.0	242		3	
		5881	+10.0	155.3	+25.0	339		13	
		5878	+26.0	171.3	+24.5	48		3	
		5877	+44.0	189.3	-7.0	630		28	
		5880	+61.0	206.3	+24.0	194	2,859	16	
May 14...	8 58	5890	-75.0	58.4	-13.5	291		1	Mt. Wilson.
		5892	-70.0	63.4	-16.0	291		4	
		5889	-48.0	85.4	-10.0	242		5	
		5888	-34.0	99.4	-11.0	485		13	
		5887	-11.0	122.4	-19.0	24		7	
		5886	-7.0	126.4	+16.5	194		7	
		5883	+3.0	136.4	-24.0	242		1	
		5881	+22.0	155.4	+23.0	242		13	
		5878	+38.0	171.4	+23.0	24		1	
		5891	+39.0	172.4	+9.0	36		2	
		5877	+56.0	189.4	-7.0	630		22	
		5880	+75.0	208.4	+23.0	48	2,749	7	
May 15...	9 0	5890	-61.0	59.1	-14.0	388		1	Do.
		5892	-57.0	63.1	-15.0	291		9	
		5889	-34.0	86.1	-10.0	291		7	
		5888	-20.0	100.1	-11.0	630		22	
		5887	+1.0	121.1	-19.5	24		5	
		5886	+7.0	127.1	+16.0	121		2	
		5883	+15.0	135.1	-24.0	242		1	
		5881	+35.0	155.1	+23.0	170		10	
		5878	+50.0	170.1	+23.0	24		1	
		5877	+69.5	189.6	-8.0	485	2,666	6	
May 16...	11 6	(*)	-70.0	35.7	-12.0	48		4	U. S. Naval.
		5890	-45.0	60.7	-14.0	291		1	
		5892	-43.0	62.7	-16.0	242		18	
		5889	-19.0	86.7	-9.5	291		10	
		5888	-5.0	100.7	-11.0	582		14	
		5886	+21.0	126.7	+17.0	97		2	
		5883	+30.0	135.7	-23.0	242		2	
		5881	+47.0	152.7	+24.0	97		7	
		5878	+64.0	169.7	+24.0	24		1	
		5877	+84.0	189.7	-7.0	485	2,399	4	
May 17...	11 4	(*)	-56.0	36.5	-12.0	97		10	Do.
		5890	-32.0	60.5	-13.0	242		1	
		5892	-28.0	64.5	-15.0	145		12	
		5889	-7.0	85.5	-9.5	194		5	
		5888	+7.0	99.5	-11.0	436		4	
		5886	+35.0	127.5	+17.0	97		1	
		5883	+44.0	136.5	-23.0	194		2	
		5881	+60.0	152.5	+25.0	73	1,478	2	
May 18...	9 14	5894	-60.0	0.3	-16.0	194		9	Mt. Wilson.
		5893	-44.0	36.3	-13.5	194		9	
		5890	-20.0	60.3	-13.0	242		1	
		5892	-16.0	64.3	-15.0	145		8	
		5889	+6.0	86.3	-10.5	194		5	
		5888	+20.0	100.3	-11.0	436		10	
		5886	+48.0	128.3	+17.0	73		1	
		5883	+57.0	137.3	-24.0	194	1,672	2	
May 20...	11 17	5896	-70.0	342.7	-31.0	6		3	U. S. Naval.
		5895	-67.0	355.7	-26.0	61		1	
		5894	-55.0	357.7	-16.5	630		8	
		5893	-15.0	37.7	-13.5	436		34	
		5890	+7.0	59.7	-13.0	206		1	
		5892	+12.0	64.7	-15.0	48		4	
		5889	+34.0	86.7	-10.0	194		4	
		5888	+47.0	99.7	-11.0	291		3	
		5886	+75.0	127.7	+17.0	97		1	
		5883	+85.0	137.7	-24.0	194	2163	1	

Date	East- ern stand- ard time	Mt. Wilson group No.	Heliographic Diff. in longi- tude	Longi- tude	Latitu- de	Spot or group	Total for each day	Spot count	Observatory
1938									
May 21...	h. m.								
	10 21	5897	-88.0	312.0	+6.0	12		1	U. S. Naval.
		5896	-58.0	342.0	-31.0	12		2	
		5894	-42.0	358.0	-16.5	630		13	
		5895	-42.0	358.0	-27.0	267		11	
		5893	-2.0	38.0	-13.5	533		28	
		5890	+20.5	60.5	-13.5	206		1	
		5892	+24.0	64.0	-15.0	12		4	
		5880	+47.0	87.0	-9.5	170		3	
		5888	+61.0	101.0	-10.0	291	2133	3	
May 22...	12 30	5897	-70.0	315.6	+7.0	36		3	Do.
		5896	-44.0	341.6	-31.0	6		1	
		5899	-37.5	348.1	-14.5	12		1	
		5895	-29.0	356.6	-27.0	218		22	
		5894	-27.5	358.1	-16.5	533		23	
		5898	-17.0	8.6	+9.0	48		9	
		5893	+11.0	36.6	-14.0	388		28	
		5890	+33.0	58.6	-13.5	194		1	
		5892	+39.5	65.1	-13.5	12		3	
		5889	+61.0	86.6	-9.5	194		2	
		5888	+74.0	99.6	-10.0	339	1980	2	
May 23...	13 47	5903	-75.0	296.7	+11.0	2		2	Do.
		5897	-56.0	315.7	+7.0	145		9	
		5895	-16.0	355.7	-27.0	194		15	
		5894	-15.0	356.7	-16.5	533		26	
		5898	-0.5	11.2	+9.0	630		35	
		5902	+9.0	20.7	-27.0	97		6	
		5901	+10.0	21.7	+10.0	73		5	
		5893	+26.0	37.7	-13.0	194		10	
		5890	+48.0	59.7	-13.0	194		1	
		5889	+75.0	86.7	-9.0	145	2399	2	
May 24...	11 44	5904	-79.5	280.1	+18.0	48		1	Mt. Wilson.
		5903	-63.0	296.6	+10.0	97		11	
		5897	-44.0	315.6	+6.0	48		5	
		5895	-2.5	357.1	-27.5	194		19	
		5894	-1.0	358.6	-16.5	727		40	
		5898	+12.0	11.6	+8.5	970		68	
		5902	+21.0	20.6	-28.0	73		12	
		5901	+23.0	22.6	+10.0	97		11	
		5893	+38.0	37.6	-13.0	194		22	
		5890	+60.0	59.6	-13.0	194	2642	1	
May 25...	12 40	5906	-70.0	275.8	-30.0	24		1	U. S. Naval.
		5905	-68.0	277.8	+21.0	97		4	
		5904	-67.0	278.8	+18.0	48		2	
		5903	-50.0	295.8	+10.5	73		4	
		5897	-30.5	315.3	+7.0	12		2	
		5895	+10.0	355.8	-26.0	121		19	
		5894	+13.5	359.3	-17.0	582		35	
		5898	+26.0	11.8	+9.0	1067		6	
		5902	+34.0	19.8	-27.0	121		6	
		5901	+37.0	22.8	+11.0	73		9	
		5893	+52.0	37.8	-12.0	121		1	
		5890	+74.0	59.8	-13.0	194	2533	1	
May 27...	10 23	5908	-40.0	257.7	+26.0	16		3	Mt. Wilson.
		5905	-34.0	281.7	+20.0	48		5	
		5904	-36.0	279.7	+15.0	24		3	
		5903	-19.0	296.7	+10.5	24		3	

PROVISIONAL SUNSPOT RELATIVE NUMBERS FOR MAY 1938

[Dependent alone on observations at Zurich and its station at Aross]

[Data furnished through the courtesy of Prof. W. Brunner, Eidgen. Sternwarte, Zurich
Switzerland]

May 1938	Relative numbers	May 1938	Relative numbers	May 1938	Relative numbers
1-----	Ec 115	11	149	21	-----
2-----	134	12	ad 143	22	a -----
3-----	EWaacc 160	13	151	23	b? 119
4-----	aad -----	14	ad 135	24	Maac 172
5-----	123	15	a 131	25	161
6-----	a 138	16	105	26	Mc 152
7-----	d 136	17	Eac 91	27	126
8-----	EMccd 153	18	ad 87	28	-----
9-----	d 156	19	95	29	EMcc 104
10-----	bd 151	20	Eac -----	30	89?
				31	Eacd 91

Mean, 26 days = 129.5.

Middle, large bright chromospheric eruption in central zone in May 24, observed at 16° 05' to 16° 15', C. G. T.

a = Passage of an average-size group through the central meridian.

b = Passage of a large group or spot through the central meridian.

c = New formation of a group developing into a middle-sized or large center of activity; E, on the eastern part of the sun's disk; W, on the western part; M, in the central circle zone.

d = Entrance of a large or average-sized center of activity on the east limb.

AEROLOGICAL OBSERVATIONS

[Aerological Division, D. M. LITTLE in Charge]

By B. FRANCIS DASHIELL

The mean free-air data, given in table 1, based on 842 airplane and radiometeorograph observations made during the month of May 1938, includes the basic meteorological elements of barometric pressure (P), temperature (T), and relative humidity (RH), all recorded at certain geometric heights.

These "means," computed by the customary method of differences, are omitted when less than 15 observations have been made at the surface and less than 5 at a standard height. However, at those standard heights lying within the limits comprising the monthly vertical range of the tropopause, 15 or more observations are required. For further details, see "Aerological Observations," in the January 1938, MONTHLY WEATHER REVIEW.

Reference to chart I shows that departures of the mean surface temperature above normal during May 1938 were moderate, reaching 4° (F) over the northwestern and southeastern coastal regions, particularly western Washington and eastern Georgia. Elsewhere temperatures remained close to normal, being somewhat above throughout the southern States, entire Mississippi Valley and Pacific coast, and slightly subnormal in the northern Plains and Rocky Mountain States, the Ohio Valley and north Atlantic States.

The highest mean free-air temperatures for the month occurred over Maxwell Field, Ala., and Pensacola, Fla., at 0.5 and 1 kilometer; over El Paso, Tex., at 1.5 and 2 kilometers; over El Paso and Kelly Field, Tex., at 2.5 and 3 kilometers; over Kelly Field at 4 kilometers; and over Kelly Field and Pensacola, Fla., at 5 kilometers. The highest mean free-air temperature (20.8° C.) occurred over Maxwell Field, Ala., at 0.5 kilometer, while the lowest of the month was -15.7° C. over Lakehurst, N. J., at 5 kilometers. Elsewhere, the lowest temperatures for the month were recorded over Boston, Mass., at all levels,

being equally over only Lakehurst, N. J., at 4 kilometers, and exceeded at 5 kilometers. Low temperatures also occurred over Sault Ste. Marie, Mich., at all levels, and at 3 and 4 kilometers along a belt extending across the northern tier of states. Billings, Mont., was colder at 4 and 5 kilometers (-14.7° C. at 5 kilometers) than any other station in this belt west of Boston, Mass., to the Pacific coast.

Mean free-air temperatures for May were seasonally higher in every case than during April. However, over Pensacola, Fla., at 4 kilometers, the temperature equaled that observed the preceding month, and at Boston, Mass., at 2 kilometers, and Lakehurst, N. J., at 2.5 kilometers, the mean was very little higher during May. The rest of the country was warmer than in April; this being outstanding at all levels over Sault Ste. Marie, Mich., and to a less marked degree over Fargo, N. Dak., and at 0.5, 1, 1.5, 2, 2.5, and 3 kilometers over Barksdale Field, La., and Maxwell Field, Ala. The greatest difference in May over April was noted at Sault Ste. Marie, Mich., at 1.5 kilometers (8.2° C.); over Fargo, N. Dak., at 0.5 kilometer (6.0° C.); over Barksdale Field, La., and Maxwell Field, Ala., at 1 kilometer (5.1° C. and 6.3° C., respectively). Smaller excesses occurred over Spokane, Wash., and Chicago, Ill., but at greater heights.

Isobaric charts, prepared from the mean barometric pressure in millibars, as shown in table 1, indicate that a statistical center of low pressure existed during the month over New England, having moved eastward from the position it occupied during April. Boston, Mass., showed the lowest mean pressure. But the area extended westward sufficiently to include Sault Ste. Marie, Mich., and Fargo, N. Dak., at all levels above 2 kilometers. A tendency toward low pressure existed also over the Pacific Northwest (Seattle, Wash.) at 0.5, 1, 1.5, and 2 kilometers. The

pressure generally was high over the southeastern States, particularly over Pensacola, Fla., at all levels. At 2.5 kilometers and up, pressures were uniformly distributed east and west, but increasing slightly toward the Gulf coast and Mexican border. During May pressures varied little from those recorded in April, except for a slight decrease at 0.5 kilometer, and increases at 2.5, 3, and 5 kilometers. Other levels remained about the same during both months.

Free-air relative humidity, as in April, remained lowest in the southwestern States, centering over El Paso, Tex., up to and including 3 kilometers; above that height the driest air was located over San Diego, Calif. Over the northeastern States, the humidity was moderately high at all levels up to 3 kilometers. At 4 and 5 kilometers, the humidity was highest over Salt Lake City, Utah, and Billings, Mont. Along the middle Atlantic coast, at all levels, the humidity was unusually low as compared with the areas to the west and north. Outstanding in this region was Washington, D. C., where the humidity was lower than for several months, at the higher levels. At 5 kilometers, over Washington, the humidity was found to equal the low humidities over El Paso and Kelly Field, Tex.

Free-air resultant winds, based on pilot-balloon observations made near 5 a. m. (75th meridian time) during the month of May, are shown in table 2. These resultant winds indicated, quite generally, nearly normal directions at all levels except over the northwestern portion of the United States. This was noticeable, particularly, over Medford, Oreg., at 1.5, 2, 2.5, and 3 kilometers, and Seattle, Wash., at 0.5, 1, 1.5, 2, and 4 kilometers. The resultant wind velocities at Medford and Seattle remained light. Elsewhere, outstanding departures from normal were confined to the standard levels immediately over the surface.

At Seattle, Wash., the resultant winds departed consistently by rotating in a clockwise direction north from normal at all levels above the surface. These directions at the standard levels from 0.5 to 4 kilometers, inclusive, were: 284°, 322°, 300°, 315°, 278°, 282°, and 337°, as compared to the normals of 205°, 235°, 236°, 248°, 242°, 253°, and 261°, respectively. However, in spite of this more northerly departure the resultant velocities at Seattle, Wash., showed only slight increases of approxi-

mately 1 m. p. s. up to 2 kilometers; they were equally less than normal at 2.5, 3, and 4 kilometers.

Somewhat similar conditions existed also over Spokane, Wash., Billings, Mont., Oakland, Calif., and, for a few levels, over Medford, Oreg. The departures at Spokane and Oakland, were not so marked as at Seattle, Wash. But, at Medford, Oreg., the largest departures at several consecutive levels in the United States occurred during the month at 1.5, 2, and 2.5 kilometers. The current resultant directions at those levels were 14°, 359°, and 352°, as compared to the normals of 79°, 243°, and 253°, respectively. At Spokane, Wash., moderate increases of velocity over the normal were recorded, but at Medford, Oreg., and Oakland, Calif., the resultant velocities varied only slightly from the normal.

Greatest departures from normal, other than those at Medford, Oreg., occurred at Sault Ste. Marie, Mich., at 1 kilometer. Here the current difference, rotated in a counterclockwise direction from normal, was 171°. Pensacola, Fla., showed a difference of 115° at 0.5 kilometer when rotated clockwise; and Fargo, N. Dak., rotated clockwise from normal, was 152° at 0.5 kilometer. Fairly stable conditions, with least departures at all levels, but less than normal when rotated counter-clockwise, existed over Detroit, Mich., during the month. At Boston, Mass. and Houston, Tex., all departures below 2.5 kilometers were slightly north of normal, while above that level they were south of normal. Elsewhere over the United States the winds were nearly normal at all levels. Resultant velocity departures exceeding normal were noticeable at Atlanta, Ga., and Sault Ste. Marie, Mich. But the greatest occurred over Newark, N. J., at 2, 2.5, and 3 kilometers. At 2.5 kilometers this departure was 6.8 m. p. s. A less-than-normal departure occurred over Fargo, N. Dak., at 4 kilometers. Of the resultant winds over the entire country during May, 20 percent showed an easterly component at 0.5 kilometer but diminishing steadily to only 4 percent at 2.5 kilometers, then becoming 100 percent westerly at and above 3 kilometers.

Table 3 shows the maximum free-air winds during May. At Huron, S. Dak., high wind velocities occurred. On the 12th a velocity of 54 m. p. s. was recorded at 10.2 kilometers, and again on the 13th the highest for the country, 57.6 m. p. s., occurred at 4.8 kilometers. Other high velocities existed over Albuquerque, N. Mex., and Modena, Utah.

TABLE 1.—Mean free-air barometric pressures (*P*) in mb., temperatures (*T*) in °C., and relative humidities (*R. H.*), in percent, obtained by airplanes and radiometeorographs during May 1938

Stations	Altitude (meters) m. s. l.																											
	Surface				500			1,000			1,500			2,000			2,500			3,000			4,000			5,000		
	Number of obs.	P	T	R. H.	P	T	R. H.	P	T	R. H.	P	T	R. H.	P	T	R. H.	P	T	R. H.	P	T	R. H.	P	T	R. H.	P	T	R. H.
Barksdale Field, La. ¹ (52 m)	31	1,007	18.9	87	956	19.6	68	902	17.5	59	850	15.2	53	802	12.8	48	754	10.2	47	710	7.3	46	628	0.1	50	---	---	---
Billings, Mont. ¹ (1,090 m)	30	890	8.5	71	---	---	---	---	---	---	847	9.2	58	797	6.0	58	749	2.4	60	704	-1.3	65	630	-8.2	69	544	-14.7	63
Boston, Mass. ¹ (5 m)	18	1,011	10.0	81	952	8.4	77	896	6.1	76	843	3.2	74	792	0.5	72	744	-1.5	70	699	-3.7	67	614	-9.6	60	539	-15.5	59
Cheyenne, Wyo. ¹ (1,873 m)	29	809	6.4	79	---	---	---	---	---	---	797	7.7	69	749	5.2	67	705	2.3	64	621	-5.6	64	546	-13.4	63	---	---	---
Coco Solo, C. Z. ¹ (15 m)	25	1,009	25.0	91	954	23.8	88	902	21.5	87	851	18.9	87	802	16.6	81	756	14.3	75	712	11.7	72	631	5.8	70	559	-0.1	71
El Paso, Texas. ¹ (1,193 m)	31	878	18.0	28	---	---	---	---	---	---	847	19.4	27	800	16.4	27	753	13.0	26	709	9.0	26	627	0.9	28	552	-6.9	33
Fargo, N. Dak. ¹ (274 m)	31	980	8.2	81	954	9.5	69	897	7.5	66	844	5.2	66	794	3.2	66	746	0.5	70	701	-2.0	66	616	-7.0	54	542	-12.8	53
Kelly Field, Tex. ¹ (206 m)	26	990	20.7	83	957	20.0	77	903	17.7	74	851	15.9	65	803	14.4	54	756	12.1	42	711	8.8	41	629	1.7	42	555	-5.9	39
Lakehurst, N. J. ¹ (39 m)	20	1,009	9.9	84	954	12.0	55	899	9.8	51	845	6.9	54	795	3.5	57	747	0.1	58	702	-3.1	56	617	-9.6	51	543	-15.7	43
Maxwell Field, Ala. ¹ (52 m)	28	1,009	20.4	80	958	20.6	61	905	18.1	59	852	15.0	58	804	12.0	52	757	9.1	47	712	6.2	46	629	0.0	41	555	-6.2	38
Mitchell Field, N. Y. ¹ (29 m)	29	1,010	10.9	84	955	11.0	68	899	9.4	61	846	7.4	60	797	4.9	66	748	2.8	62	704	0.0	62	620	-5.3	55	---	---	---
Nashville, Tenn. ¹ (180 m)	30	993	17.2	83	957	18.5	71	903	16.2	70	850	12.9	71	802	9.7	69	754	6.5	65	709	3.7	57	626	-1.8	48	532	-7.8	44
Norfolk, Va. ¹ (10 m)	16	1,013	16.1	89	957	18.2	56	903	15.2	55	850	11.6	59	800	7.9	65	752	4.7	64	708	1.7	56	624	-4.9	47	549	-11.1	40
Oakland, Calif. ¹ (2 m)	31	1,016	11.7	83	958	12.4	74	902	14.8	49	850	12.5	42	800	9.4	39	752	6.2	40	708	3.1	39	624	-2.9	38	550	-9.4	37
Oklahoma City, Okla. ¹ (391 m)	31	967	16.4	84	954	17.7	73	900	16.6	64	849	15.1	54	800	12.5	52	753	9.0	55	708	5.6	55	625	-1.0	60	551	-8.1	58
Omaha, Nebr. ¹ (300 m)	31	976	13.4	81	953	14.7	67	898	12.9	64	846	10.3	62	797	7.6	56	749	4.7	55	704	1.8	58	621	-4.4	57	547	-11.1	54
Pearl Harbor, T. H. ¹ (6 m)	31	1,016	21.5	81	960	20.5	77	905	17.7	84	853	15.8	84	804	13.4	76	757	12.4	68	713	11.0	42	632	7.8	25	560	2.4	30
Pensacola, Fla. ¹ (13 m)	30	1,015	19.7	92	959	20.4	70	906	18.5	58	854	15.8	51	805	12.9	47	757	9.8	44	713	7.1	39	629	0.6	40	556	-5.6	36
St. Thomas, V. I. ¹ (8 m)	30	1,017	26.5	71	961	21.8	84	907	18.2	86	855	15.8	77	806	13.6	68	759	11.2	62	714	8.6	58	633	3.6	50	559	-1.4	40
Salt Lake City, Utah. ¹ (1,288 m)	31	899	9.2	70	---	---	---	---	---	---	848	11.7	54	798	9.2	52	750	5.7	55	706	1.8	61	622	-5.6	68	547	-12.7	65
San Diego, Calif. ¹ (10 m)	29	1,014	15.4	80	957	13.1	81	902	15.4	57	850	13.4	50	801	11.4	41	754	8.8	38	709	6.0	31	625	0.1	25	552	-7.1	22
Sault Ste. Marie, Mich. ¹ (221 m)	31	987	7.0	79	955	9.0	67	898	7.7	64	845	5.2	65	795	2.2	67	746	-0.7	68	701	-2.9	62	616	-8.1	54	542	-14.2	50
Scott Field, Ill. ¹ (135 m)	25	997	13.8	85	955	16.8	62	900	14.0	65	848	10.7	68	798	8.1	64	750	5.0	63	706	1.9	60	622	-4.0	48	549	-10.4	44
Seattle, Wash. ¹ (10 m)	23	1,019	14.7	59	961	11.1	61	905	9.3	54	852	6.9	46	801	4.5	37	753	1.6	37	708	-1.4	34	623	-7.8	32	---	---	---
Selfridge Field, Mich. ¹ (177 m)	29	992	10.0	83	955	11.3	71	899	9.4	70	846	6.9	67	796	4.1	67	748	1.4	64	703	-1.3	60	618	-6.9	52	544	-13.5	51
Spokane, Wash. ¹ (597 m)	31	945	8.7	69	---	---	---	---	---	---	848	9.7	45	798	6.0	49	750	2.3	55	705	-1.2	59	620	-7.8	63	545	-13.8	61
Washington, D. C. ¹ (13 m)	29	1,014	13.8	76	956	14.0	59	902	12.0	57	849	8.8	60	799	6.1	57	751	3.4	48	706	0.4	49	622	-5.6	39	547	-11.9	35
Wright Field, Ohio. ¹ (244 m)	27	985	11.7	85	956	13.6	72	900	12.1	68	848	9.5	69	798	6.6	69	750	4.2	63	706	2.0	51	622	-4.0	49	548	-10.1	46
Burbank Calif. ¹ (220 m)	31	988	11.4	82	956	13.0	70	901	14.0	52	849	12.0	47	800	9.8	42	753	7.5	36	708	5.0	34	625	-0.6	29	551	-7.3	26
Chicago, Ill. ¹ (187 m)	31	991	11.8	82	954	12.6	70	899	10.4	68	846	7.8	65	796	5.5	61	748	2.8	58	704	0.2	60	620	-6.0	54	545	-12.3	47

Observations taken about 4 a. m. 75th meridian time, except by Navy stations along the Pacific coast and Hawaii where they are taken at dawn.

*Observations by radiometeorograph. Stations not so marked have observations by airplane.

1 Army.

2 Weather Bureau.

3 Navy.

NOTE.—None of the means included in this table are based on less than 15 surface or 5 standard-level observations.

TABLE 2.—Free-air resultant winds (meters per second) based on pilot-balloon observations made near 5 a. m. (E. S. T.) during May 1938

[Wind from N=300°, E=90°, etc.]

Altitude (meters) m. s. l.	Albuquerque, N. Mex. (1,554 m)		Atlanta, Ga. (309 m)		Billings, Mont. (1,088 m)		Boston, Mass. (15 m)		Cheyenne, Wyo. (1,873 m)		Chicago, Ill. (192 m)		Cincinnati, Ohio (187 m)		Detroit, Mich. (204 m)		Fargo, N. Dak. (283 m)		Houston, Tex. (21 m)		Key West, Fla. (11 m)		Medford, Oreg. (410 m)		Nashville, Tenn. (194 m)	
	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity
Surface.....	319	1.9	271	1.3	285	1.9	321	1.5	283	2.6	195	0.4	200	0.1	229	0.7	360	0.7	125	1.2	123	2.2	184	0.3	203	1.4
500.....	---	---	269	4.0	---	---	314	3.9	---	---	227	2.3	220	2.5	235	2.2	333	1.1	162	6.2	125	4.0	253	0.4	256	4.5
1,000.....	---	---	270	6.1	---	---	298	4.6	---	---	247	3.8	267	5.0	267	4.1	308	1.6	169	5.6	135	3.5	331	1.8	260	5.9
1,500.....	---	---	273	6.2	---	---	294	7.1	---	---	253	4.7	264	6.4	271	3.8	284	1.3	170	3.4	142	1.8	14	1.6	264	6.9
2,000.....	298	3.7	270	6.3	287	4.1	293	7.7	288	3.2	278	6.0	255	6.9	280	4.3	261	1.8	205	3.6	142	1.4	359	1.4	252	7.4
2,500.....	285	4.8	275	6.6	291	5.3	283	8.5	282	3.9	277	6.7	271	7.1	272	5.1	290	3.9	242	2.0	158	1.0	352	1.2	259	7.0
3,000.....	278	6.1	267	7.4	294	6.5	280	9.8	283	6.7	287	8.7	256	5.5	283	5.2	299	2.9	266	1.8	224	1.4	324	2.3	262	6.0
4,000.....	265	9.2	249	4.5	282	8.2	280	12.0	292	8.1	---	---	245	7.4	277	6.9	347	0.6	289	3.9	261	4.7	260	3.6	291	5.7
5,000.....	265	11.2	---	---	299	3.0	---	---	261	7.6	---	---	---	---	286	10.4	---	---	283	6.0	267	4.2	263	6.2	---	---

Altitude (meters) m. s. l.	Newark, N. J. (14 m)		Oakland, Calif. (8 m)		Oklahoma City, Okla. (402 m)		Omaha, Nebr. (306 m)		Pearl Har- bor, Territo- ry of Hawai- i ¹ (68 m)		Pensacola, Fla. ¹ (24 m)		St. Louis, Mo. (170 m)		Salt Lake City, Utah (1,292 m)		San Diego, Calif. (15 m)		Sault Ste. Marie, Mich. (198 m)		Seattle, Wash. (14 m)		Spokane, Wash. (603 m)		Washing- ton, D. C. (10 m)	
	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity
Surface.....	334	1.2	246	1.2	164	2.5	180	0.7	50	2.4	291	1.2	193	1.1	151	2.5	27	0.9	78	1.4	142	1.3	122	0.7	304	0.8
500.....	323	4.5	284	1.7	162	4.3	202	1.1	61	8.2	235	2.3	226	4.3	---	---	336	2.3	110	3.6	284	0.3	---	---	319	3.8
1,000.....	312	5.5	341	4.3	200	8.4	240	2.0	70	---	228	2.9	220	2.5	---	---	339	3.6	120	1.2	322	1.6	243	3.1	310	3.9
1,500.....	296	8.3	7	4.4	224	6.5	255	3.4	82	2.7	230	3.3	268	6.9	154	2.4	326	2.8	247	1.2	300	1.6	267	4.6	293	6.7
2,000.....	289	12.3	354	4.4	250	7.3	261	4.7	179	1.1	195	3.1	271	7.3	259	1.3	304	2.7	247	2.4	315	2.4	263	4.3	263	8.8
2,500.....	285	16.2	336	4.8	253	7.1	269	5.6	216	1.8	223	1.7	262	7.1	283	2.4	281	3.8	290	2.9	275	3.0	273	4.0	271	10.2
3,000.....	278	14.8	342	7.0	264	5.4	289	5.6	224	1.5	250	1.1	250	6.1	282	3.9	306	5.5	306	5.5	282	2.9	263	3.4	263	10.5
4,000.....	---	---	329	7.2	302	8.7	298	6.6	270	0.3	266	4.3	296	6.3	273	6.8	---	---	310	9.2	337	4.6	272	4.7	279	9.1
5,000.....	---	---	---	---	303	10.7	---	---	284	2.7	---	---	301	5.0	279	10.5	---	---	---	---	---	---	---	---	---	---

TABLE 3.—Maximum free-air wind velocities (meters per second) for different sections of the United States based on pilot-balloon observations during May 1938

Section	Surface to 2,500 meters (m. s. l.)				Station	Between 2,500 and 5,000 meters (m. s. l.)				Station	Above 5,000 meters (m. s. l.)				Station
	Maximum velocity	Direction	Altitude (m), m. s. l.	Date		Maximum velocity	Direction	Altitude (m), m. s. l.	Date		Maximum velocity	Direction	Altitude (m), m. s. l.	Date	
Northeast ¹	40.4	NW	2,440	17	Newark, N. J.	40.4	NW	3,600	2	Albany, N. Y.	35.2	NW	5,940	1	Albany, N. Y.
East-Central ²	36.1	SW	1,870	23	Cincinnati, Ohio	42.4	NW	4,680	16	Greensboro, N. C.	36.2	N	10,440	31	Greensboro, N. C.
Southeast ³	32.0	W	2,250	15	Jacksonville, Fla.	38.0	W	3,640	14	Atlanta, Ga.	35.2	NNW	9,280	14	Key West, Fla.
North-Central ⁴	30.5	WSW	1,320	2	Bismark, N. Dak.	57.6	WSW	4,800	13	Huron, S. Dak.	54.0	N	10,200	12	Huron, S. Dak.
Central ⁵	34.7	S	970	4	St. Louis, Mo.	38.0	NW	3,140	15	St. Louis, Mo.	36.8	W	6,460	8	Wichita, Kans.
South-Central ⁶	29.7	S	1,360	3	Brownsville, Tex.	29.1	SSW	3,730	3	Amarillo, Tex.	39.4	NNW	10,660	26	Del Rio, Tex.
Northwest ⁷	26.8	WSW	2,160	12	Pendleton, Oreg.	33.5	NW	3,970	13	Missoula, Mont.	47.0	W	7,340	30	Medford, Oreg.
West-Central ⁸	37.5	SSW	2,280	18	Modena, Utah	41.4	NW	4,780	2	Sacramento, Calif.	52.8	WSW	8,420	19	Modena, Utah
Southwest ⁹	32.8	WSW	2,300	12	Havre, Mont.	34.4	NW	4,700	4	Fresno, Calif.	55.0	WSW	6,500	1	Albuquerque, N. Mex.

¹ Maine, Vermont, New Hampshire, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Pennsylvania, and northern Ohio.

² Delaware, Maryland, Virginia, West Virginia, southern Ohio, Kentucky, eastern Tennessee, and North Carolina.

³ South Carolina, Georgia, Florida, and Alabama.

⁴ Michigan, Wisconsin, Minnesota, North Dakota, and South Dakota.

⁵ Indiana, Illinois, Iowa, Nebraska, Kansas, and Missouri.

⁶ Mississippi, Arkansas, Louisiana, Oklahoma, Texas (except El Paso), and western Tennessee.

⁷ Montana, Idaho, Washington, and Oregon.

⁸ Wyoming, Colorado, Utah, northern Nevada, and northern California.

⁹ Southern California, southern Nevada, Arizona, New Mexico, and extreme west Texas.

RIVERS AND FLOODS

[River and Flood Division, MERRILL BERNARD in charge]

By BENNETT SWENSON

Precipitation during May 1938 was above normal in practically all sections, except the Southwest and extreme West. Kansas and Minnesota received more than twice the normal amount, and in the Ohio Valley and most of the Great Plains the rainfall was substantially above normal. Severe local flooding resulted principally in the rivers which drain the Kansas and Minnesota regions.

Upper Mississippi Basin.—High water prevailed over much of this section during the month. This was due to two distinct periods of heavy rains over Minnesota, Iowa, and Wisconsin during May 2-9 and May 14-28. In the first period the heaviest rainfall was centered north of the Twin Cities in Minnesota. This resulted in abnormally high lake levels and caused disastrous flood conditions in the Aitken County area in Minnesota. The report on the floods in this area was not received in time for inclusion in the May issue of the REVIEW, but will be included in the next issue.

The following report was submitted by the official in charge of the La Crosse, Wis., district, which consists of the Mississippi River and tributaries from below St. Paul, Minn., to and including La Crosse:

High water prevailed during the entire month of May in the district. The highest stage at La Crosse since April 1922 occurred when the crest reached 13.7 feet, although the crest in March 1936 was only 0.1 foot lower. Practically the same relative differences prevailed at Winona, Minn., for those years. In the upper section of the district from Lake Pepin to Hastings, Minn., the flood conditions were comparable to 1922, and crest stages averaged only 0.3 to 0.4 foot lower than in that year. The high water in May 1938 was characterized by two gradual rises covering the periods 1-13 and 18-27. During the first period the average rise was 5.0 feet and during the second period 1.2 feet throughout the district. The second rise was really a secondary crest produced by additional heavy rains just after it had begun to fall after the first period of prolonged rains.

The present occurrence of high water was by no means due to melting snow in the headwaters, as the crest resulting from this run-off appeared throughout the district from March 26 to March 31. It was due wholly to two distinct periods of heavy rains extending from the 2d to the 9th and from the 14th to 28th. The first of these periods resulted in a large reserve of water in the section north of the Twin Cities, resulting in turn in abnormally high lake levels and causing disastrous flood conditions in the Aitken, Minn., area. The May totals of rainfall show an unusual condition in that

the amounts increased from La Crosse northward. The reverse is generally the case, larger amounts occurring in the southern section of the district. The following May rainfall totals will indicate this as well as to show that the amounts vary in excess of normal amounts from +1.11 inches at La Crosse to +7.28 at Hastings: La Crosse, 4.86; Dam No. 7, 5.90; Hatfield, 5.75; Dam No. 6, 4.87; Winona, 6.87; Dam No. 5A, 8.24; Beaver, 4.52; Dam No. 5, 6.12; Dam No. 4, 7.11; Durand (Chippewa), 9.41; Reads, 8.52; Red Wing, 9.20; Dam No. 3, 9.38; Hastings, 10.95. The lower Chippewa Valley had as large an excess as the vicinity of Hastings, and the Chippewa River contributed materially to high-water stages from Reads, Minn., southward, especially in the secondary crest occurring at Winona and La Crosse on the 24th. The Chippewa at Durand, Wis., discharged slightly over 50,000 second-feet at the flood stage of 11 feet on the 7th and 21st. The Black River contributed materially to flood stage at La Crosse on the 24th and 25th, caused by the release of a large volume of water from the Hatfield power dam.

The flood conditions in the Dubuque, Iowa, district, comprising the Mississippi River and tributaries from below La Crosse, Wis., to and including Dubuque, are reported by the official in charge at that place:

The Mississippi was unusually high for May, the average stage at Dubuque being 13.2 feet. There were two separate rises, the second beginning 5 days after the occurrence of the first crest. The river was falling at the beginning of the month, the lowest stage, 9.19, being reached in the afternoon of the 4th. It then began to rise due to general high-water conditions throughout the upper Mississippi Valley. The Wisconsin River crest passed downstream before the arrival of the upper Mississippi crest, and thereby reduced the severity of this rise at points near and below the mouth of the Wisconsin River. The crest gave a stage of 15.7 feet at Dubuque on the 20th. Further substantial rains, particularly in northern Wisconsin, produced new floods in many of the tributaries above La Crosse. In this case the times of arrival of crests from above La Crosse and from the Wisconsin River bore normal relations to each other, which favored somewhat higher stages than in the case of the preceding crest. An additional factor was the occurrence at Dubuque of still further heavy rainfall on the 27th. The final result was a crest of 17.15 feet on May 30. This was the highest river stage at Dubuque since April 1922.

The approach of the crest in the extreme upper Mississippi, together with further local heavy rains, caused the lower half of the upper Mississippi to slightly exceed flood stage, principally from Quincy to Alton, Ill., during the last few days of the month. Low places along the river were overflowed but only slight damage occurred.

Missouri and Arkansas Basin.—Unusually heavy rains, centered mainly over Kansas, during May resulted in widespread floods in that area. In the Missouri River drainage, floods occurred principally in the Solomon, Osage, Gasconade, and the Missouri River itself at Hermann and St. Charles, Mo. In the Arkansas River drainage, the floods were confined mainly to the Cottonwood, Neosho, Cimarron, Verdigris, Ninescah, North and South Canadian, and in the Arkansas River from Ralston, Okla., to Dardanelle, Ark.

The overflows of the Solomon River were slight and little or no damage resulted.

The Cottonwood River overflowed slightly at Emporia, Kans., on the 7th and again on the 13th, but heavy rains on the 19th resulted in a serious flood in this river and in creeks in Chase and Lyon Counties, with damage, mostly to growing crops, estimated at more than \$200,000. The river was above bankful from the 19th to the 26th at Emporia and crested at 24.4 feet (4.4 feet above flood stage) on the 24th.

The Osage River reached a high stage near the Kansas-Missouri boundary, with a loss of \$76,200. At La Cygne, Kans., the river reached a crest of 26.0 feet on May 26 (5.0 feet above bankful stage).

The Neosho River flood was still in progress at the close of the month and a report concerning it will be included in the next issue of the REVIEW.

Heavy rains on the 19th over south-central and south-eastern Kansas resulted in high water in the Walnut, Verdigris, and Ninescah Rivers and many smaller streams in that area, and caused damages totaling approximately \$370,000.

High water in the North and South Canadian Rivers from May 19-31 caused damages slightly exceeding \$40,000.

The heavy discharges from the tributaries in Kansas and eastern Oklahoma brought stages in the Arkansas above flood stage as far downstream as Dardanelle, Ark., with an estimated loss of about \$100,000.

Lower Mississippi Basin.—The Tallahatchie River which has been in flood in the vicinity of Swan Lake, Miss., since January 28, subsided during May, passing below flood stage on May 11—about 4,000 acres of cleared land was under water much of this time.

West Gulf of Mexico Drainage.—Flooding continued from April in the Sabine and lower Trinity Rivers, remaining above flood stage until May 9. The Trinity crested at Liberty, Tex., on May 1, with a stage of 26.5 feet, and at Logansport, La., on the Sabine River, May 3-4, with a stage of 27.4 feet. The report of the damage was included in the report for April.

The Guadalupe River was above flood stage at Victoria, Tex., at the beginning of May and this was followed by two more rises on May 10 and 17. The latter rise was caused by a local heavy rain. The amount of damage caused by the floods in the Guadalupe River from April 26 to May 17 has been estimated at about \$236,000, largely to prospective crops.

Colorado River Basin.—Light floods occurred in the Eagle River, Roaring Fork River, and Gunnison River, all tributaries of the Colorado River in Colorado, during the month. The floods in the two former streams occurred at the close of the month but in the Gunnison River there were three separate rises, on the 1st, 15th, and the 27th. No damage of consequence has been reported.

Pacific Slope Drainage.—High stages prevailed in the San Joaquin Basin during the month. The snow depths in the Sierra Nevada Mountains near the end of March

were greater than for many years past. This, together with the fact that the March rains left the streams high at the beginning of the spring snow melting season, accounts for the high water during May.

Kings River was above flood stage at Piedra, Calif., from May 13 to 19, and from May 24, with the latter rise in progress at the close of the month. The San Joaquin was also out of its banks at the end of the month.

The Columbia River and a few of its tributaries exceeded flood stage late in the month. As the floods in both the San Joaquin and Columbia basins continued into June a full report will be made later.

Table of flood stages during May 1938

[All dates in May unless otherwise specified]

River and station	Flood stage	Above flood stages—dates		Crest	
		From—	To—	Stage	Date
ST. LAWRENCE DRAINAGE					
Lake Huron					
Cass: Vassar, Mich.....	Feet 13	24	24	Feet 13.2	24
EAST GULF OF MEXICO DRAINAGE					
Pearl: Pearl River, La.....	12	Mar. 27	8	17.0	Apr. 13
MISSISSIPPI SYSTEM					
Upper Mississippi Basin					
Chippewa: Durand, Wis.....	11	7	7	11.0	7
Wisconsin:		21	22	11.3	21, 22
Merrill, Wis.....	11	5	5	11.0	5
Knowlton, Wis.....	12	5	6	13.4	5
Bourbeuse: Union, Mo.....	12	20	21	13.1	21
Meramec:		25	26	12.4	25
Sullivan, Mo.....	11	23	25	16.8	24
Pacific, Mo.....	11	23	27	16.8	25
Valley Park, Mo.....	14	24	28	22.5	25
Mississippi:					
Fort Ripley, Minn.....	10	8	19	10.8	10, 11
La Crosse, Wis.....	12	24	25	12.0	24, 25
Quincy, Ill.....	14	22	24	14.1	24
Hannibal, Mo.....	13	20	(1)	14.3	24
Louisiana, Mo.....	12	22	(1)	13.8	25
Alton, Ill.....	21	26	28	21.4	27
Chester, Ill.....	27	28	28	27.1	28
Missouri Basin					
Solomon: Beloit, Kans.....	18	37	37	21.4	27
Osage:		31	31	20.0	31
Oseola, Mo.....	20	25	(1)	24.9	30
Lakeside, Mo.....	60	22	30	60.7	24, 25
St. Thomas, Mo.....	23	23	31	25.8	27
Gasconade: Jerome, Mo.....	15	24	25	15.6	24
Missouri:					
Hermann, Mo.....	21	24	26	21.8	25
St. Charles, Mo.....	25	24	28	26.9	26
Ohio Basin					
Hocking: Athens, Ohio.....	17	21	23	18.4	22
West Fork of White:		24	25	18.5	25
Ellistons, Ind.....	18	23	25	19.0	24
Edwardsport, Ind.....	12	23	28	16.6	25
Ohio: Cairo, Ill.....	40	29	June 3	41.2	31, June 1
White Basin					
Current: Doniphan, Mo.....	10	24	26	13.4	25
Black: Black Rock, Ark.....	14	28	31	15.2	29
White:					
Calico Rock, Ark.....	18	23	25	24.4	23
Batesville, Ark.....	23	24	27	29.0	24
Georgetown, Ark.....	21	Mar. 31	3	(7)	
Clarendon, Ark.....	26	Apr. 3	June 8	29.7	June 1
Arkansas Basin					
Cimarron: Perkins, Okla.....	11	20	20	12.8	20
Verdigris: Sagesyah, Okla.....	35	23	25	13.0	24
		25	30	37.3	29
		6	7	21.0	7
Cottonwood: Emporia, Kans.....	20	12	13	20.6	13
		19	26	23.5	21
				24.4	24

See footnotes at end of table.

Table of flood stages during May 1938—Continued

[All dates in May unless otherwise specified]

River and station	Flood stage	Above flood stages—dates		Crest	
		From—	To—	Stage	Date
MISSISSIPPI SYSTEM—continued					
Arkansas Basin—Continued					
Neosho:	<i>Feet</i>			<i>Feet</i>	
Neosho Rapids, Kans.-----	22	20	26	24.2	2
		12	13	25.0	12, 13
LeRoy, Kans.-----	23	19	28	27.8	23
		30	30	23.6	30
		14	14	15.5	14
Iola, Kans.-----	15	20	(¹)	20.5	20
Oswego, Kans.-----	17	22	(¹)	23.3	22
Fort Gibson, Okla.-----	22	26	26	22.0	26
		31	(¹)		
North Canadian:					
		5	8	7.5	5
Canton, Okla.-----	6	18	21	11.0	18
		22	26	8.3	22
		Apr. 28	2	10.2	Apr. 28
Yukon, Okla.-----	8	4	12	11.2	4
		19	(¹)	12.6	19
(East) Oklahoma City, Okla.-----	14	22	23	14.6	22, 23
Arkansas:					
Balston, Okla.-----	16	22	23	16.4	22, 23
Webbers Falls, Okla.-----	23	24	28	23.9	24
Fort Smith, Ark.-----	22	23	29	25.0	23
Van Buren, Ark.-----	22	23	30	25.1	25, 26
Dardanelle, Ark.-----	22	25	28	22.8	25
Red Basin					
Ouachita: Monroe, La.-----	40	Apr. 16	5	(¹)	
Black: Jonesville, La.-----	50	Apr. 7	14	(¹)	
Lower Mississippi Basin					
St. Francis: Flisk, Mo.-----	20	25	27	22.4	25
Tallahatchie: Swan Lake, Miss.-----	26	Jan. 28	11	31.0	Apr. 12, 13
Yazoo: Yazoo City, Miss.-----	29	Apr. 10	10	30.53	Apr. 30
Mississippi:					
Angola, La.-----	45	Apr. 17	7	(¹)	
Baton Rouge, La.-----	35	Apr. 16	8	(¹)	
Plaquemine, La.-----	31	Apr. 17	8	(¹)	
Donaldsonville, La.-----	28	Apr. 20	6	(¹)	
Reserve, La.-----	22	Apr. 27	1	(¹)	

Table of flood stages during May 1938—Continued

[All dates in May unless otherwise specified]

River and station	Flood stage	Above flood stages—dates		Crest	
		From—	To—	Stage	Date
MISSISSIPPI SYSTEM—continued					
Atchafalaya Basin					
Atchafalaya:	Feet			Feet	
Melville, La.	37	Apr. 17	8	38.5	Apr. 27-1
Atchafalaya, La.	25	Apr. 27	2	25.0	Apr. 27-2
Morgan City, La.	6	4	4	6.0	4
		6	7	6.1	7
WEST GULF OF MEXICO DRAINAGE					
Sabine: Logansport, La.	25	Apr. 20	10	27.4	3, 4
Trinity: Liberty, Tex.	24	Apr. 9	9	26.5	Apr. 30, 1
		Apr. 25	2	28.7	Apr. 30
Guadalupe: Victoria, Tex.	21	9	11	23.0	10
		16	17	27.3	17
Rio Grande: Espanola, N. Mex.	7	19	21	7.1	21
GULF OF CALIFORNIA DRAINAGE					
Colorado Basin					
Eagle: Eagle, Colo.	5	29	(1)	5.4	31
Roaring Fork: Carbondale, Colo.	5	28	(1)	6.2	30
North Fork of Gunnison: Paonia, Colo.	9	Apr. 30	1	9.3	1
		14	18	10.0	16
		27	30	9.8	29
		Apr. 23	2	10.8	1
Gunnison: Delta, Colo.	9	14	19	10.2	16
		27	(1)	11.2	30
PACIFIC SLOPE DRAINAGE					
San Joaquin Basin					
Kings: Piedra, Calif.	10	13	19	11.9	15
		24	(1)		
San Joaquin: Lathrop, Calif.	17	28	(1)		
Columbia Basin					
Kootenai: Bonners Ferry, Idaho.	31	29	June 1	31.5	30
Clearwater: Kamiah, Idaho.	12	1	1	12.3	1
		24	June 3	14.6	29
Willamette: Portland, Oreg.	18	29	(1)	20.6	31
		3	7	16.1	5
Columbia: Vancouver, Wash.	15	26	(1)		

¹ Continued into next month.² Crest occurred previous month.

WEATHER ON THE ATLANTIC AND PACIFIC OCEANS

[The Marine Division, W. E. HURD acting in charge]

NORTH ATLANTIC OCEAN, MAY 1938

By H. C. HUNTER

Atmospheric pressure.—As in the preceding month most of the North Atlantic had pressure greater than normal during May, though the departures from normal were not marked this month. The greatest positive departures were 0.13 inch at Lerwick, Shetland Islands, and 0.12 inch at Madeira. The central part of the North Atlantic had pressure somewhat above normal, and near Iceland also; around the Greater Antilles and over much of the Gulf of Mexico there was a slight excess.

From near southern Greenland to the waters east of Florida and the Bahamas there was a moderate deficiency of pressure.

Among the barometer readings so far secured from vessels the extremes of the month are found to be 30.53 and 28.82 inches. The higher reading was noted on the forenoon of the 23d, by the British steamship *Tucurina*, about 500 miles to west-northwest of the northwestern coast of Spain. The lower reading was noted early on the 4th about 400 miles northeast of St. Johns, Newfoundland, by the British liner *Duchess of Richmond*.

TABLE 1.—Averages, departures, and extremes of atmospheric pressure (sea level) at selected stations for the North Atlantic Ocean and its shores, May 1938

Stations	Average pressure	Departure	High-est	Date	Low-est	Date
	<i>Inches</i>	<i>Inch</i>	<i>Inches</i>		<i>Inches</i>	
Jullianehaab, Greenland	29.81	-0.04	30.32	6	29.28	1
Reykjavik, Iceland	29.96	+0.04	30.51	4	29.47	31
Lerwick, Shetland Islands	29.93	+0.13	30.39	2, 4	29.44	29
Valencia, Ireland	29.95	+0.00	30.39	22	29.38	26
Lisbon, Portugal	30.08	+0.11	30.32	12	29.68	5
Madeira	30.13	+0.12	30.27	11, 12	29.94	5
Horta, Azores	30.26	+0.10	30.46	18	30.08	12
Belle Isle, Newfoundland	29.87	-0.02	30.44	29	29.28	2
Halifax, Nova Scotia	29.93	-0.04	30.50	30	29.38	16
Nantucket	29.93	-0.06	30.40	31	29.20	15
Hatteras	29.96	-0.05	30.23	31	29.58	14
Bermuda	30.06	-0.05	30.34	26	29.82	5
Turks Island	30.01	+0.01	30.08	1, 2	29.92	6
Key West	29.98	+0.01	30.14	2	29.85	5
New Orleans	29.98	+0.01	30.15	1	29.68	7

NOTE.—All data based on a. m. observations only, with departures compiled from best available normals related to time of observation, except Hatteras, Key West, Nantucket, and New Orleans, which are 24-hour corrected means.

Cyclones and gales.—The month was less stormy than the average May, particularly over the eastern regions. From the 30th meridian to the west coast of Europe there

was no storm of more than slight importance felt after the 3d until the 28th.

A Low centered over Labrador on the 1st intensified on the 2d when the center was a little north of the Strait of Belle Isle and remained nearly stationary on the 3d, while a secondary developed over the southwestern part of the Grand Banks. One vessel, while a moderate distance to southward of the Grand Banks, on the evening of the 3d, met a whole gale (force 10). The morning of the 4th found a single though well-marked center located about latitude 48° north, longitude 45° west. Unusually high pressure over and near Iceland blocked advance of this Low, and for about a week longer, with usually lessening strength in spite of a few reinforcements from the American continent, it dominated the general region of the Grand Banks, gales being noted in connection with it on several days.

Another Low of considerable importance advanced from the Central States to reach the middle Atlantic coast late on the 14th, and showed marked strength from the 15th to the 17th, as it moved slowly northeastward near the New England and Nova Scotia coasts. Two small motor fishing-boats were wrecked on Marthas Vineyard, three of the four men on board being lost, and considerable other damage to shipping was reported. Well off shore to southward two vessels met force-10 winds during the 15th or the early hours of the 16th. These two reports and the report for the 3d of May, already mentioned, are the only Atlantic reports yet received for the month with wind force as great as 10.

By the 18th some decrease of energy was evident, and the storm had become the southern part of a large low-pressure system extending from the southwest part of the Grand Banks to southern Greenland. Within the next 48 hours this southern portion drew away to northward and the main steamship routes ceased to be affected by it.

Late in the month the waters around and for moderate distances to southwestward and westward of the British Isles experienced stormy weather, several vessels reporting difficulties. The Low concerned in these developments

showed considerable energy by the morning of the 29th and thereafter, till late on the 30th, was centered about in the latitude of central Scotland, with usually greater extent in an east-west direction than in others. By the 31st a northeastward movement was evident, with some loss of strength.

Fog.—As is usually the case, the May fogginess showed a considerable increase over April in about all the areas of moderate to marked frequency. There was mainly more than normal occurrence of fog from Cape Hatteras northeastward to the central Grand Banks; also for a moderate distance to westward of the coasts of France and Ireland.

Over the northern and eastern portions of the Grand Banks and in mid-Atlantic fog was less prevalent than usual, several squares in the chief lanes to northern Europe furnishing either but one report of occurrence or no report whatever.

To southward of 35° latitude a very few, widely scattered reports of fog are found. One rather unusual location, a few hundred miles east of Bermuda, reported fog on the 15th.

For waters close to the United States coast and indeed for the whole North Atlantic, the 5° -square 35° to 40° north, 70° to 75° west, led in days of occurrence with 17. The first 9 days of the month found considerable fog here, while the period from the 18th to 29th inclusive had fog almost every day.

The square, 40° to 45° N., 65° to 70° W., which has parts of the New England and Nova Scotia coasts, had fog on 16 days, distributed through the month about as in the square previously mentioned.

The leading square for the Grand Banks area was that from 40° to 45° N., 50° to 55° W., with 12 days; here the period from 13th to 28th included nearly all the fog that was recorded.

In waters not far west of Europe the leading square was 45° to 50° N., 15° to 20° W., with 7 days. In this part of the ocean practically all the fog was noted within the period from the 10th to 23d.

OCEAN GALES AND STORMS, MAY 1938

Vessel	Voyage		Position at time of lowest barometer		Gale began May—	Time of lowest barometer May—	Gale ended May—	Lower barometer	Direction of wind when gale began	Direction and force of wind at time of lowest barometer	Direction of wind when gale ended	Direction and highest force of wind	Shifts of wind near time of lowest barometer
	From—	To—	Latitude	Longitude									
NORTH ATLANTIC OCEAN													
Nemaha, Am. S. S.	Rotterdam	Tampa	44 54 N.	19 12 W.	1	11a, 1	2	29.65	W	NW, 6	NNW	NW, 9	
Leto, Du. S. S.	Galveston	Hull	40 25 N.	47 52 W.	3	7p, 3	3	29.33	SSW	SSW, 10	SW	SSW, 10	SSW, WSW.
Amsterdam, Du. S. S.	Batton Rouge	Avonmouth	40 15 N.	49 25 W.	3	11p, 3	3	29.45	W	W, 8	W	W, 8	W-NW.
Pres. Harding, Am. S. S.	Cobb	New York	42 55 N.	44 56 W.	3	4a, 4	5	29.24	SSW	SSW, 9	NW	SSW, 9	SSE-W.
Black Condor, Am. S. S.	Antwerp	do.	45 30 N.	43 00 W.	4	8a, 4	4	29.34	S	SSW, 9	WSW	SSW, 9	S-SW.
Steel Ranger, Am. S. S.	Gibraltar	Wilmington, N. C.	35 00 N.	45 54 W.	5	5p, 5	5	29.83	SW	SW, 8	SW	SW, 8	
Gand, Belg. S. S.	New Orleans	Havre	39 19 N.	56 08 W.	9	11p, 8	9	29.63	WNW	WNW, 7	WNW	WNW, 8	WNW-NNW.
Sundance, Am. S. S.	Charleston	Avonmouth	40 35 N.	48 51 W.	9	9a, 9	11	29.54	NW	WNW, 6	W	NW, 9	WNW-NNW.
Speybank, Br. M. S.	Huelva	Philadelphia	37 11 N.	46 12 W.	9	10p, 9	9	29.83	SW	SW, 8	W	SW, 8	SW-W.
Manhattan, Am. S. S.	Cobb	New York	43 56 N.	44 32 W.	10	4a, 10	10	29.30	W	W, 9	WNW	W, 9	W-NW.
Black Gull, Am. S. S.	New York	Antwerp	44 24 N.	42 30 W.	9	8a, 10	11	29.25	W	W, 9	WNW	W, 9	W-NW.
Vincent, Am. S. S.	Dunkirk	New York	46 36 N.	36 20 W.	10	2p, 10	11	29.11	SSW	WSW, 8	W	WSW, 9	SSW-WSW.
Tuscaloosa City, Am. S. S.	Avonmouth	Portland, Maine	47 54 N.	35 50 W.	10	4p, 10	11	29.07	SW	SW, 6	W	W, 8	SW-WNW.
Exmoor, Am. S. S.	Lisbon	New York	36 20 N.	58 40 W.	9	4p, 10	10	29.67	SW	SW, 7	SW	SW, 8	
American Trader, Am. S. S.	London	Boston	46 29 N.	32 37 W.	10	7p, 10	11	29.19	SW	SW, 9	W	WSW, 9	SW-WNW-WSW.
Bilderdyk, Du. S. S.	Rotterdam	New York	48 54 N.	21 27 W.	11	9a, 11	11	29.53	SW	SW, 8	SW	SW, 8	S-SW.
Syros, Am. S. S.	New Orleans	Bremen	41 30 N.	45 12 W.	12	9p, 11	12	29.80	W	WSW, 5	NW	WNW, 8	SSW-W.
San Jacinto, Am. S. S.	New York	San Juan	38 30 N.	73 05 W.	15	Mdt, 14	15	29.43	W	SSW, 7	W	W, 9	SE-W.
Speybank, Br. M. S.	Huelva	Philadelphia	38 25 N.	70 50 W.	14	5p, 15	15	29.46	SE	SW, 6	SW	SE, 10	SW-W.
Mormacstar, Am. S. S.	Trinidad	New York	35 50 N.	71 50 W.	15	3a, 16	16	29.58	W	W, 8	WNW	W, 10	W-WNW.
City of Hamburg, Am. S. S.	Southampton	Norfolk	41 04 N.	60 07 W.	16	4p, 16	16	29.47	SW	SSW, 7	SSW	SSW, 9	SSW-WSW.
Bilderdyk, Du. S. S.	Rotterdam	New York	41 19 N.	55 28 W.	16	4p, 17	16	29.62	S	WNW, 4	S	S, 8	SSW-WNW-WSW.
Florida, Fr. S. S.	Havre	do.	36 57 N.	49 35 W.	17	6p, 18	18	29.88	S	W, 7	WSW	SSW, 8	WSW-W.
Caledonia, Br. S. S.	New York	Mobile	47 15 N.	47 20 W.	22	9a, 22	23	29.93	S	S, 6	SSW	S, 8	S-SW.
Schuykill, Br. M. S.	Belfast	Aruba	15 01 N.	10 15 W.	29	Noon, 29	29	29.43	W	S, 6	W	W, 8	S-W.
Rhode Island, Am. M. S.	Port Arthur	Liverpool	37 20 N.	65 30 W.	30	5p, 30	31	29.97	ENE	ENE, 7	NNE	ENE, 8	None.
Europa, Ger. S. S.	Cherbourg	New York	41 36 N.	49 54 W.	31	10p, 31	31	29.53		N, 9		N, 9	
NORTH PACIFIC OCEAN													
Hikawa Maru, Jap. M. S.	Vancouver	Yokohama	50 12 N.	177 18 E.	1	Noon, 1	1	29.42		NNE, 8		NNE, 8	
Pres. Jefferson, Am. S. S.	Seattle	do.	51 59 N.	158 30 W.	2	3a, 2	3	29.14	SW	SW, 6	W	WNW, 9	SW-W.
Hoegh Hood, Nor. M. S.	Estero Bay	Tsushima	35 18 N.	123 00 W.	3	4a, 3	3	30.10		NW, 8		NW, 8	
Tai Yin, Nor. M. S.	Yokohama	Los Angeles	47 13 N.	108 04 W.	10	5a, 10	11	28.98	W	NE, 5	WSW, 7	WSW, 8	NE-NW.
Meigs, U. S. A. T.	Manila	San Francisco	19 20 N.	129 02 E.	13	8a, 14	15	29.24	NNE	SSE, 5	S	SSW, 12	SSW-SSE-WSW.
Tulsagas, Am. S. S.	do.	do.	41 37 N.	163 17 W.	14	1a, 16	15	29.60	S	S, 7	S	S, 8	S-SW.
Manulani, Am. S. S.	Honolulu	do.	36 54 N.	125 36 W.	18	4a, 18	18	30.01		N, 8		N, 8	
Nitro, U. S. N.	San Diego	Balboa	18 54 N.	105 00 W.	24	5p, 23	24	29.84	E	ENE, 2	E	E, 8	
Hermion, Nor. M. S.	Mojl	Portland, Oreg.	48 18 N.	171 06 W.	27	1p, 26	27	29.15		W, 6		SSW, 8	
Tsuyama Maru, Jap. S. S.	Yokohama	Los Angeles	43 52 N.	162 00 W.	29	1a, 30	30	29.77		WSW, 8		WSW, 8	

1 Position approximate.

2 Barometer uncorrected.

NORTH PACIFIC OCEAN, MAY 1938

By WILLIS E. HURD

Atmospheric pressure.—For the third consecutive month, beginning with March 1938, pressure continued to be abnormally low over Aleutian waters and abnormally high in the neighborhood of Midway Island. Dutch Harbor in May 1938 had an average pressure of 29.51 inches, which is 0.33 inch below the normal; while Midway Island had an average pressure of 30.18, which is 0.13 above the normal. The Aleutian cyclone persisted throughout May and the lowest pressure reading of the month at Dutch Harbor, 28.80 inches, occurred as late as the 27th. The North Pacific anticyclone was practically ocean-wide in extent, with pressures above normal generally in middle latitudes.

Extratropical cyclones and gales.—Numerous cyclones appeared over northern waters of the North Pacific Ocean during May 1938. Although their combined result was an extraordinarily low average pressure for the month over the eastern Aleutians, yet none was of more than light to moderate energy. The most severe gale thus far reported by any ship in central and higher latitudes was only of force 9, barometer 29.14, experienced by the American steamer *President Jefferson* during the night of May 2-3, in the vicinity of 52° N., 158° W.

Practically all gales observed in connection with cyclones in extratropical waters occurred to the northward of the 40th parallel, between longitudes 175° E., and

TABLE 1.—Averages, departures, and extremes of atmospheric pressure at sea level, North Pacific Ocean, May 1938, at selected stations

Station	Average pressure	Departure from normal	High-est	Date	Low-est	Date
	Inches	Inch	Inches		Inches	
Point Barrow	29.89	-0.20	30.44	6, 7	29.52	12
Dutch Harbor	29.51	-0.33	30.02	25	28.80	27
St. Paul	29.62	-0.22	30.06	14	28.98	27
Kodiak	29.71	-0.13	30.14	26	28.90	11
Juneau	30.00	+0.01	30.39	14	28.92	11
Tatoosh Island	30.11	+0.10	30.44	13	29.76	27
San Francisco	30.00	+0.01	30.23	4	29.77	16
Mazatlan	29.86	+0.01	29.94	18	29.78	30
Honolulu	30.00	-0.05	30.12	2	29.90	14
Midway Island	30.18	+0.13	30.33	19, 20	30.06	16
Guam	29.85	-0.03	29.92	11	29.77	6
Manila	29.79	+0.02	29.83	5, 20, 21, 24	29.71	9
Hong Kong	29.78	0.00	29.98	9	29.40	3
Naha	29.85	+0.03	30.03	9	29.71	17, 18
Titijima	29.98	+0.07	30.15	14	29.77	18, 22

NOTE.—Data based on 1 daily observation only, except those for Juneau, Tatoosh Island, San Francisco, and Honolulu, which are based on 2 observations. Departures are computed from best available normals related to time of observation.

155° W. The greater number of these did not exceed 8 in force. They were reported on the 1st to 3d, 10th, 14th, 15th, 27th, and 30th. During the prevalence of the deepest cyclone of the month, over the eastern Aleutians, from the 26th to 28th, while only one force-8 gale was reported, yet there were winds of force 7 in the vicinity on all three dates.

On the 3d and 18th northerly gales of force 8 occurred off the central California coast along the eastern slope of the oceanic anticyclone.

Tropical cyclones and gales.—Subjoined is a report by the Rev. Bernard F. Doucette, S. J., Weather Bureau, Manila, P. I., of two typhoons which affected Philippine waters during May 1938. The typhoon of May 7-18 is noted as having been of hurricane intensity on the 14th. Early that morning the U. S. A. T. *Meigs*, in and near the vicinity of 19°20' N., 129°02' E., encountered winds of force 12 which lasted for several hours. Gales of lower force continued on ship through most of the 14th and even at midnight they had diminished only to force 7.

Fog.—Fog was the most important meteorological element of the month on the North Pacific, particularly in east longitudes, where the conditions of late spring and early summer usually bring it with considerable frequency. In several 5° squares along the western part of the northern steamer routes, and to the west-northwestward of Midway Island on the middle routes, fog occurred on 5 to 6 or more days. The American steamer *President Taft*, eastbound from Yokohama, reported such extensive fog banks east of Honshu on the 4th to longitude 166° E., in latitude 33° N., on the 7th, that a constant lookout had to be kept on account of it. East of midocean, fog was more widely scattered and less frequent. Off the California coast, ships reported fog on the 22d to 25th. During dense fog late on the 23d the American steamer *Walter A. Luckenbach* and the Japanese motorship *Arimasan Maru* collided outside of Los Angeles Harbor breakwater, with the result that much damage was done to both vessels.

TYPHOONS AND DEPRESSIONS OVER THE FAR EAST, MAY 1938

BERNARD F. DOUCETTE, S. J.

(Weather Bureau, Manila, P. I.)

Typhoon, April 28-May 5, 1938.—A low-pressure area appeared during the afternoon hours of April 28 about 120 miles east of northern Mindanao and moved, as a depression, along a west-northwesterly course across the Visayan Islands into the China Sea, where, April 30 to May 2, it inclined slightly to the northwest, thus reaching the Paracel Islands. There were no strong winds, nor did the pressure fall very much, and the disturbance seemed to be a depression of little importance.

Intensification began during the afternoon of May 2 as the center changed its course to the north-northeast. Moving more rapidly now, and inclining to the north, the typhoon (there was no doubt that it had intensified to this stage) passed about 100 miles southeast of Hong Kong and entered the China coast close to and west of Swatow shortly before dawn, May 4. It weakened somewhat after this as it was followed for two days, finally disappearing northwest of Shanghai.

The first indications of the strengthening of the storm came with observations received from the S. S. *Tjibadak*. May 3 at 8 a. m. when in latitude 17.3° N., longitude 117.3° E., a pressure of 750.83 mm (29.560 in.) with south-southwest winds, force 6, was reported. From Hong Kong, May 3, at 2 p. m., a pressure of 750.6 mm (29.551 in.) was the lowest of the synoptic observations received.

There are some interesting aspects to be found in a study of the upper winds over these regions as the depression intensified and became a typhoon. The critical period was May 2 and 3, as the depression recurved to the north-northeast and intensified. Indo-China reported only a few ascents before May 1, showing southeast, south, and south-southwest winds with velocities of 10 to 20 k. p. h. below 1,000 m. No pilots were broadcast on May 2. A northeasterly current, less than 20 k. p. h.,

backing to the northwest quadrant in the afternoon, was indicated on May 3. Above 1,500 m, northwest and southwest winds were found, with velocities of 10 to 35 k. p. h. Over Hong Kong, there were east winds, veering aloft to southeast and increasing in strength, from 15 to 50 k. p. h., on May 2, to values over 50 k. p. h. on May 3. On April 29, there were weak east and southeast winds over the Philippines. On the following days, the velocities increased, and from May 1 to 4, velocities from 30 to 60 k. p. h. were maintained. Zamboanga, it should be noted, had northwesterly winds at various levels on May 1 and 2. Over Malaya, westerly and southwesterly winds gradually predominated and increased in strength on April 29 and 30, so that on May 1 to 3, a definite current of air was flowing from the west-southwest and west with velocities from 10 to 30 k. p. h. These data indicate that strengthening winds from the southeast and southwest quadrants had some part in the intensification of the depression.

Typhoon, May 7-18, 1938.—A low pressure area formed over the ocean regions north of Palau, first appearing on May 7. A definite circulation with weak winds around a center and with pressure values slightly below normal, apparently of minor importance, best describes the disturbance, which moved along a westerly course to the Philippines. On May 9 it was central over the Visayan Islands and Luzon. The next day, still a low-pressure area, it was moving in a northwesterly direction with a tendency to incline northward, the center passing along central and northern Luzon. Up to this time, the lowest pressure reported was 753.5 mm (29.665 inches) as the storm moved over the Archipelago.

The morning weather map of May 12 indicated the center about 100 miles east-southeast of Aparri, after passing in a northeasterly direction across northern Luzon into the Pacific, this taking place a short distance north of Palanan, Isabela Pr. During the night, intensification had begun and the storm now manifested the strength of a typhoon. An easterly movement of about 300 miles in 24 hours preceded a change of path to the northeast and then to the north (the afternoon of May 14), the latter change occurring near latitude 20° N., longitude 130° E. On May 16 the center was located not far from latitude 24° N., longitude 130° E., from which position it again moved in a northeasterly direction, gradually inclining to the east-northeast as it disappeared east of northern Japan during the afternoon hours of May 18.

The U. S. A. T. *Meigs*, enroute from Manila to the United States, was traveling along a course almost parallel to that of the typhoon and north of the center. On May 13 and 14, when the typhoon changed its course to the northeast and later to the north, the ship came under the influence of the typhoon winds and seas, encountering heavy seas and winds of hurricane force. Of the many observations sent to the Observatory, that with the lowest barometer reading was made, most likely at noon, May 14 (the time of the observation could not be definitely determined from the radiogram, and verification could not be obtained in time for the preparation of this article), when the ship was in latitude 19° 12' N., longitude 129° 10' E., the value being 29.18 inches (741.17 mm), with south-southwest winds, force 6.

The pilot balloon observations made at Philippine stations during the course of this storm indicate an important factor in the intensification of the disturbance. While the center was over the Archipelago, the circulation was not strong, due very likely to the friction between the air and the land. The southwest quadrant winds at Cebu and Zamboanga were about 15 k. p. h. and at the same time, Manila and Aparri had east and southeast quadrant

winds, velocities from 15 to 30 k. p. h. After May 11, however, when the center was over the ocean regions east of northern Luzon, the circulation was not checked so much by land areas and intensification could be expected. Furthermore, the southwest quadrant winds were allowed to accelerate because of the low hills of southern Luzon, namely the country south of the locality of Infanta, Tayabas Pr. Thus the southwest current of air was allowed to flow more freely and help in the intensification of the storm. The velocities at Cebu and Zamboanga increased threefold during this period, and at Manila, when the winds shifted to the southwest, velocities from 30 to 50 k. p. h. were recorded. Malaya pilots (those which

were copied from the weather broadcasts) on the days preceding May 11 showed east quadrant winds intermingled with southwest quadrant winds, and velocities, with very few exceptions, less than 20 k. p. h. On May 11 and 12, a definite southwest quadrant current prevailed, with velocities from 15 to 25 k. p. h., which, on the following days weakened and had south-southwest and northwest directions intermingled with the southwesterly directions. There is very good evidence in the pilot balloon observations during these days that the topographical features of southern Luzon helped in the intensification by allowing the southwesterly winds to flow more rapidly toward the typhoon center.

CLIMATOLOGICAL TABLES

CONDENSED CLIMATOLOGICAL SUMMARY

In the following table are given for the various sections of the climatological service of the Weather Bureau the monthly average temperature and total rainfall; the stations reporting the highest and lowest temperatures, with dates of occurrence; the stations reporting the greatest and least total precipitation; and other data as indicated by the several headings.

The mean temperature for each section, the highest and lowest temperatures, the average precipitation, and the greatest and least monthly amounts are found by using all trustworthy records available.

The mean departures from normal temperatures and precipitation are based only on records from stations that have 10 or more years of observations. Of course, the number of such records is smaller than the total number of stations.

TABLE 1.—Condensed climatological summary of temperature and precipitation by sections, May 1938

[For description of tables and charts, see REVIEW, January, p. 29]

Section	Temperature								Precipitation					
	Section average	Departure from the normal	Monthly extremes						Section average	Departure from the normal	Greatest monthly		Least monthly	
			Station	Highest	Date	Station	Lowest	Date			Station	Amount	Station	Amount
Alabama.....	72.9	+1.6	2 stations.....	99	120	Florence.....	42	9	3.48	-0.64	Winfield.....	7.48	Millry.....	0.62
Arizona.....	65.0	-1.0	do.....	114	31	Fort Valley.....	13	7	2.20	-1.13	Fredonia.....	2.36	23 stations.....	.00
Arkansas.....	70.1	+0.9	Dumas.....	97	130	Thornburg.....	34	9	4.62	-1.36	Eureka Springs.....	15.27	Arkansas City.....	.87
California.....	61.1	-1.3	2 stations.....	113	14	2 stations.....	4	3	4.41	-1.53	Colfax.....	2.52	28 stations.....	.00
Colorado.....	51.9	-1.3	3 stations.....	95	28	3 stations.....	3	17	2.48	+1.58	Akron.....	5.09	Ignacio.....	.16
Florida.....	76.8	+1.2	Arcadia.....	103	26	2 stations.....	46	15	4.10	+1.12	De Funiak Springs.....	10.38	Clearwater.....	.68
Georgia.....	72.8	+1.2	4 stations.....	102	121	Blairsville.....	38	10	3.47	+1.02	Midville.....	7.86	Alapaha.....	1.13
Idaho.....	51.8	-1.2	3 stations.....	96	126	Warren.....	6	2	1.55	-1.10	Grangeville.....	3.78	Bonniers Ferry.....	.25
Illinois.....	63.0	+1.3	2 stations.....	92	20	Morris.....	25	13	5.14	+1.07	Edwardsville.....	7.94	Cairo.....	2.71
Indiana.....	62.6	+1.4	Princeton.....	94	20	Collegeville.....	25	13	5.53	+1.50	Huntingburg.....	9.02	Rochester.....	2.87
Iowa.....	59.5	-1.5	3 stations.....	89	13	Lake City.....	29	17	5.45	+1.36	Osage.....	11.25	Elkader.....	3.00
Kansas.....	63.5	-1.3	2 stations.....	99	28	Oberlin.....	26	8	7.56	+3.70	Emporia.....	16.65	Hugoton.....	2.41
Kentucky.....	65.7	+1.3	Pikeville.....	93	19	Mount Sterling.....	32	13	5.73	+1.71	Owensboro.....	8.46	Bonniers Ferry.....	2.55
Louisiana.....	74.4	+1.7	2 stations.....	95	29	2 stations.....	44	9	2.51	-2.05	Port Sulphur.....	7.34	Franklinton.....	.54
Maryland-Delaware.....	61.3	-1.1	Cumberland, Md.....	96	4	do.....	23	13	4.34	+1.93	Sines, Md.....	7.66	Snow Hill, Md.....	2.10
Michigan.....	54.8	+1.8	2 stations.....	90	3	Sidnaw.....	18	12	3.67	+1.49	Centerville.....	8.25	Sault Ste. Marie.....	1.82
Minnesota.....	53.3	-1.8	New Ulm.....	90	2	Roseau.....	18	7	6.55	+3.33	Hastings.....	10.95	Hallock.....	1.89
Mississippi.....	73.3	+1.5	Clarksdale.....	100	31	Batesville.....	40	9	2.72	-1.61	Fulton.....	12.66	Waynesboro.....	.29
Missouri.....	65.0	+1.6	Caruthersville.....	94	22	Louisiana.....	32	13	6.13	+1.35	Dean.....	12.21	Dexter.....	2.21
Montana.....	50.6	-1.2	Glasgow.....	92	27	2 stations.....	12	17	3.18	+1.02	Chessman Reservoir.....	7.67	Libby.....	.45
Nebraska.....	58.2	-1.9	Benkelman.....	97	28	Gordon.....	22	9	4.99	+1.53	Seward.....	9.80	Dalton.....	1.59
Nevada.....	55.4	-1.1	Las Vegas Airport.....	104	26	Austin.....	12	3	1.18	+1.31	Sharp.....	3.31	Carson City.....	.01
New England.....	53.6	-1.5	Manchester, N. H.....	88	5	3 stations.....	22	14	3.64	+1.29	Kingston, R. I.....	5.84	Gilman, Vt.....	1.59
New Jersey.....	59.0	-1.4	2 stations.....	89	12	2 stations.....	26	13	3.51	-1.22	Woodcliff Lake.....	4.68	Newark.....	2.63
New Mexico.....	58.6	-1.1	Orogrande.....	103	27	Red River Canyon.....	7	8	.67	-1.52	Mosquero.....	4.41	14 stations.....	.00
New York.....	55.0	-1.9	Dansville.....	89	5	Whiteface Mountain.....	18	12	3.01	-1.45	Skaneateles.....	6.62	Ogdensburg.....	1.24
North Carolina.....	67.7	+1.9	Fayetteville.....	100	6	Mount Mitchell.....	30	9	4.91	+1.83	Caroleen.....	10.32	Monroe.....	2.14
North Dakota.....	52.0	-1.4	Mott.....	88	28	4 stations.....	18	7	2.55	+1.24	Hillsboro.....	5.42	Pembina.....	1.09
Ohio.....	61.3	+1.8	3 stations.....	92	13	Medina (near).....	24	12	5.25	+1.55	Miamisburg.....	9.42	Cleveland.....	2.69
Oklahoma.....	68.8	+1.5	Hollis.....	102	29	Hooker.....	27	8	5.95	+1.22	Fairview.....	13.42	Madill.....	1.59
Oregon.....	53.1	-1.1	2 stations.....	98	25	Fremont.....	11	15	.84	-1.88	Headworks.....	3.68	3 stations.....	T
Pennsylvania.....	58.8	-1.7	Sharon.....	93	5	Coudersport.....	20	11	3.85	-1.02	Rochester.....	6.56	Gratersford.....	1.53
South Carolina.....	72.3	+1.4	Lake City.....	102	22	Long Creek (near).....	39	10	4.14	+1.56	Spartanburg.....	7.46	Heath Springs.....	1.62
South Dakota.....	55.2	-1.1	Hot Springs.....	94	28	Redig.....	18	7	3.48	+1.60	Forestburg.....	6.00	McLaughlin.....	1.74
Tennessee.....	67.8	+1.9	2 stations.....	93	19	Elkmount.....	35	16	5.81	+1.62	Tellico Plains.....	9.60	Memphis.....	2.86
Texas.....	73.5	+1.5	Fort Stockton.....	109	27	Muleshoe.....	27	8	3.08	-1.56	Houston.....	10.27	2 stations.....	.00
Utah.....	53.3	-2.0	2 stations.....	100	14	Silver Lake.....	5	5	1.80	+1.58	Silver Lake.....	5.15	La Sal.....	.04
Virginia.....	63.7	-1.4	Danville.....	96	4	2 stations.....	30	12	4.51	+1.57	Pennington Gap.....	7.39	Balcony Falls.....	2.04
Washington.....	55.3	+1.7	3 stations.....	98	124	Paradise Inn.....	19	1	1.09	-1.87	Palmer.....	6.02	White Swan.....	.00
West Virginia.....	61.1	-1.6	Glenville.....	94	5	Bayard.....	20	13	5.97	+2.01	Glenville.....	10.51	Inwood.....	3.62
Wisconsin.....	55.1	-1.1	Brodhead.....	89	2	Long Lake.....	18	12	5.06	+1.46	River Falls.....	11.89	Plymouth.....	1.41
Wyoming.....	48.4	-1.0	5 stations.....	90	127	Dome Lake.....	3	7	2.63	+1.55	Sheridan Field Station.....	7.11	Kemmerer.....	.79
Alaska (April).....	34.5	+7.9	Seclusion Harbor.....	70	23	Allakaket.....	-15	120	1.67	+1.22	Ketchikan.....	15.20	Barrow.....	.00
Hawaii.....	71.9	+1.2	Kaanapali.....	92	1	Kanalohulu.....	42	18	10.09	+4.31	Puasakamoa No. 2.....	55.00	Waimea.....	.00
Puerto Rico.....	76.5	-1.7	2 stations.....	95	113	Garzas.....	55	28	5.51	-1.72	Maricao.....	24.20	Juana Diaz.....	.21

Other dates also.

TABLE 2.—Climatological data for Weather Bureau stations, May 1938

[Compiled by Annie E. Small by official authority U. S. Weather Bureau]

District and station	Elevation of instruments			Pressure			Temperature of the air										Precipitation			Wind					Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month			
	Barometer above sea level	Thermometer above ground	Anemometer above ground	Station, reduced to mean of 24 hours	Sea level, reduced to mean of 24 hours	Departure from normal	Mean max. + mean min. + 2	Departure from normal	Maximum	Date	Minimum	Date	Mean minimum	Greatest daily range	Mean wet thermometer	Mean temperature of dew-point	Mean relative humidity	Total	Departure from normal	Days with 0.01 inch or more	Average hourly velocity	Prevailing direction	Maximum velocity										
																							Miles per hour	Direction							Date		
New England																																	
Eastport	76	67	85	29.83	29.92	-0.04	47.2	-0.5	65	31	54	33	3	40	27	43	39	78	2.12	-0.9	16	9.9	sw.	41	e.	15	8	5	18	6.7	0.0	0.0	
Greenville, Maine	1,060	4	41	28.84	29.92	-0.04	49.0	-0.9	77	31	62	22	5	36	46	44	39	68	4.53	+0.0	14	8.2	nw.	25	nw.	15	10	11	10	5.4	0.0	0.0	
Portland, Maine	103	82	117	29.81	29.93	-0.04	52.4	-0.9	71	21	60	38	13	45	23	46	40	68	4.00	+0.7	14	8.6	s.	32	ne.	15	11	11	9	5.4	0.0	0.0	
Concord	289	54	72	29.61	29.92	-0.06	54.4	-1.1	80	5	66	31	13	43	40	48	42	66	3.11	+1.1	15	6.1	so.	26	ne.	23	7	9	15	6.3	0.0	0.0	
Burlington	403	11	48	29.47	29.91	-0.06	54.0	-2.5	75	31	64	35	4	44	32	48	42	66	2.01	-0.7	13	7.4	s.	24	s.	23	6	11	14	6.5	0.0	0.0	
Northfield	876	12	60	28.96	29.93	-0.04	51.1	-1.7	75	27	64	25	4	38	47	46	41	66	2.01	-0.7	13	7.4	s.	24	s.	23	6	11	14	6.5	0.0	0.0	
Boston	29	33	62	29.89	29.92	-0.04	55.8	-1.3	81	24	64	41	5	48	28	49	43	68	4.42	+1.2	14	11.0	e.	42	ne.	15	4	10	17	6.8	0.0	0.0	
Nantucket	12	14	90	29.92	29.93	-0.06	53.2	-0.9	73	21	60	40	7	46	21	50	47	84	2.91	+1.1	10	13.7	sw.	43	e.	15	12	6	13	6.0	0.0	0.0	
Block Island	26	11	46	29.90	29.94	-0.06	53.2	-0.9	73	21	60	40	7	46	21	50	47	84	2.91	+1.1	10	13.7	sw.	43	e.	15	10	12	9	5.2	0.0	0.0	
Providence	159	215	251	29.76	29.93	-0.05	57.0	-1.5	81	24	67	39	31	47	32	50	44	66	4.49	+1.5	13	10.9	nw.	34	nw.	2	10	6	15	8.7	0.0	0.0	
Hartford	159	66	100	29.76	29.93	-0.05	57.6	-1.1	78	28	68	38	13	47	32	51	45	68	4.66	+1.1	10	8.1	s.	29	nw.	2	7	16	8	5.7	0.0	0.0	
New Haven	106	74	153	29.83	29.94	-0.05	57.6	-1.3	78	2	66	40	13	49	26	51	45	68	4.28	+0.6	10	8.5	n.	25	nw.	16	3	17	11	6.4	0.0	0.0	
Middle Atlantic States																																	
Albany	97	97	112	29.82	29.93	-0.05	57.6	-1.7	80	27	67	37	12	48	30	50	43	62	3.42	+0.5	14	7.4	s.	24	s.	20	2	18	11	6.0	0.0	0.0	
Binghamton	871	57	79	29.02	29.95	-0.03	56.5	-0.9	85	5	67	29	12	46	38	51	46	72	2.07	-1.2	11	6.4	nw.	21	nw.	17	4	7	20	7.8	0.0	0.0	
New York	314	415	454	29.60	29.93	-0.06	59.4	-1.2	78	2	68	38	12	51	28	51	46	65	3.49	+0.2	11	12.5	nw.	45	nw.	16	6	10	15	6.7	0.0	0.0	
Harrisburg	374	94	104	29.55	29.95	-0.03	61.0	-0.8	81	2	70	40	12	52	28	53	47	64	3.45	+0.0	18	7.2	w.	23	nw.	16	6	12	13	6.3	0.0	0.0	
Philadelphia	114	174	367	29.83	29.96	-0.03	61.5	-1.4	82	6	70	42	12	54	28	54	47	65	2.86	-0.4	10	11.2	e.	31	nw.	10	5	13	13	6.2	0.0	0.0	
Reading	323	283	306	29.60	29.94	-0.04	61.4	-1.1	82	5	70	41	13	53	25	53	47	63	2.24	-1.4	13	10.5	nw.	36	se.	14	6	13	12	6.0	0.0	0.0	
Scranton	805	72	104	29.08	29.94	-0.04	58.1	-1.3	84	5	68	34	14	48	31	50	43	62	3.23	-0.0	14	6.6	nw.	26	nw.	16	3	14	14	6.5	0.0	0.0	
Atlantic City	52	37	172	29.89	29.95	-0.03	59.4	+1.3	87	6	66	42	12	53	31	54	50	77	3.56	+0.5	13	14.3	do.	40	w.	15	4	11	16	7.4	0.0	0.0	
Sandy Hook	22	10	55	29.92	29.94	-0.03	58.2	-0.2	79	24	64	43	12	52	25	52	49	76	3.32	-0.4	11	12.0	w.	33	w.	15	4	11	16	6.6	0.0	0.0	
Trenton	190	89	107	29.74	29.94	-0.04	60.1	-1.0	84	6	69	39	12	51	30	53	46	66	2.95	-1.1	10	8.4	nw.	24	nw.	16	3	12	12	7.3	0.0	0.0	
Baltimore	123	100	215	29.82	29.95	-0.04	63.6	-0.8	85	21	72	45	12	55	28	56	50	66	4.86	+1.3	16	10.5	sw.	31	sw.	16	6	11	14	6.6	0.0	0.0	
Washington	112	62	85	29.83	29.95	-0.05	63.4	-0.3	86	3	72	44	13	54	37	56	50	66	3.51	-0.2	14	7.1	nw.	23	sw.	16	6	11	14	6.6	0.0	0.0	
Cape Henry	18	8	84	29.93	29.95	-0.02	65.2	+1.0	89	24	72	48	13	58	28	61	59	85	5.45	+1.9	13	12.2	sw.	37	ne.	15	7	9	15	6.3	0.0	0.0	
Lynchburg	686	144	184	29.24	29.98	-0.02	65.8	-1.5	94	4	76	47	2	56	38	57	52	66	4.13	+0.5	9	7.1	nw.	31	w.	20	6	10	19	7.2	0.0	0.0	
Norfolk	91	80	128	29.87	29.97	-0.03	67.2	+1.0	90	21	75	48	13	59	30	60	56	75	5.06	+1.2	14	9.8	ne.	37	sw.	20	6	10	19	7.2	0.0	0.0	
Richmond	144	11	52	29.82	29.96	-0.03	65.6	-0.9	90	5	75	46	12	56	37	59	55	75	4.66	+0.9	13	7.7	nw.	38	w.	23	10	10	15	5.6	0.0	0.0	
Wytheville	2,304	49	55	27.61	29.99	-0.00	60.8	-0.6	84	4	71	42	12	50	38	54	51	75	6.45	+2.8	15	6.5	w.	26	nw.	15	7	9	15	6.8	0.0	0.0	
South Atlantic States																																	
Asheville	2,253	89	104	27.67	29.99	-0.00	64.2	+1.6	89	19	75	44	11	54	31	56	53	75	3.29	-1.1	18	7.6	nw.	25	nw.	15	5	12	14	6.2	0.0	0.0	
Charlotte	779	63	86	29.15	29.98	-0.01	70.2	+1.3	93	20	80	51	13	60	27	60	55	65	4.35	+0.7	13	7.2	sw.	32	sw.	23	5	14	12	6.3	0.0	0.0	
Greensboro	886	6	56	29.05	30.00	-0.03	67.3	-0.2	92	4	78	46	1	56	36	59	54	71	3.37	-0.2	12	8.3	do.	32	sw.	23	6	12	13	6.3	0.0	0.0	
Hatteras	11	5	50	29.94	29.96	-0.05	69.7	+1.0	84	5	76	53	13	64	18	65	63	84	6.20	+2.5	12	13.0	sw.	39	w.	15	11	9	11	5.4	0.0	0.0	
Raleigh	376	103	140	29.56	29.96	-0.03	69.3	+0.8	94	4	79	49	13	60	32	61	56	70	4.60	+0.8	15	8.7	w.	32	nw.	15	11	9	11	5.0	0.0	0.0	
Wilmington	72	73	107	29.89	29.96	-0.05	72.5	+1.7	93	21	81	54	12	64	24	65	62	77	3.78	+0.3	9	9.1	sw.	29	nw.	15	16	8	10	6.1	0.0	0.0	
Charleston	48	11	92	29.93	29.98	-0.03	76.1	+3.4	99	21	84	59	16	68	25	67	63	71	3.94	+0.9	7	9.7	sw.	25	nw.	15	6	12	8	11	5.0	0.0	0.0
Columbia, S. C.	347	70	91	29.60	29.98	-0.02	73.4	+1.5	95	21	84	55	31	63	30	63	58	66	4.21	+1.1	11	8.0	do.	29	w.	5	12	8	11	5.0	0.0	0.0	
Greenville, S. C.	1,039	139	182	28.93	29.97	-0.02	69.8	+2.6	94	22	80	50	16	59	30	60	54	64	3.83	-0.2	13	7.1	sw.	26	sw.	14	6	13	12	5.9	0.0	0.0	
Augusta	182	62	77	29.77	29.96	-0.03	74.4	+2.0	96	22	85	55	12	64	30	64	59	67	4.15	+1.1	9	5.8	nw.	24	sw.	14	6	13	12	5.9	0.0	0.0	
Savannah	65	73	152	29.92	29.98	-0.02	76.8	+3.4	99	22	87	57	12	67	29	66	62	71	6.21	+3.2	15	10.2	sw.	32	nw.	24	10	12	9	5.3	0.0	0.0	
Jacksonville	43	86	110	29.95	30.00	-0.00	77.6	+2.6	99	22	87	59	12	68	26	67	62	70	7.04	+3.0	11	7.3	s.	29	sw.	24	5	18	8	5.7	0.0	0.0	
Florida Peninsula																																	
Key West	21	10	64	29.96	29.98	+0.01	80.8	+1.7	89	28	86	60	13	75	17	75	71	75	1.24	-2.3	7	8.3	se.	22	w.	11	12	11	8	5.0	0.0	0.0	
Miami	25	124	168	29.98	30.01	+0.02	78.2	+1.8	89	15	83	66	11	75	18	71	68	74	5.58	-0.6	11	8.7	se.	30	nw.	11	13	7	11	5.0	0.0	0.0	
Tampa	35	88	197	29.96	30.00	+0.01	78.6	+2.3	94	23	88	63	6	70	27	69	66	74	5.06	+2.1	7	9.1	nw.	35	do.	6	12	6	4	4.5	0.0	0.0	
Titusville	43	5	36	29.96	30.0																												

See footnotes at end of table.

TABLE 2.—Climatological data for Weather Bureau stations, May 1938—Continued

District and station	Elevation of instruments			Pressure			Temperature of the air										Precipitation			Wind				Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month			
	Barometer above sea level	Thermometer above ground	Anemometer above ground	Station, reduced to mean of 24 hours	Sea level, reduced to mean of 24 hours	Departure from normal	Mean max. + mean min. +2	Departure from normal	Maximum	Date	Mean maximum	Minimum	Date	Mean minimum	Greatest daily range	Mean wet thermometer	Mean temperature of the dew-point	Mean relative humidity	Total	Departure from normal	Days with 0.01 inch or more	Average hourly velocity	Prevailing direction							Maximum velocity		
																														Miles per hour	Direction	Date
Middle Slope	ft.	ft.	ft.	in.	in.	in.	°F. 62.2	°F. -0.3	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	% 67	in. 5.46	in. +2.1		Miles							0-10 5.9	in.	in.	
Denver.....	5,292	106	113	24.67	29.87	+0.03	56.0	-0.2	86	28	67	29	7	45	30	45	38	56	4.88	+2.7	13	8.2	s.	25	nw.	27	4	16	11	6.0	2.7	0.0
Pueblo.....	4,685	80	86	25.22	29.85	+0.02	59.2	-0.2	92	28	72	32	8	47	38	47	37	63	1.77	+2.7	7	7.7	nw.	28	sw.	1	6	17	8	5.6	1.5	0.0
Concordia.....	1,392	50	58	28.41	29.86	-0.05	61.3	-1.9	84	26	70	32	8	52	32	56	53	78	7.76	+3.6	19	8.5	s.	30	nw.	4	6	15	10	6.1	0.0	0.0
Dodge City.....	2,609	10	86	27.27	29.83	-0.04	63.1	-1.4	91	17	74	33	8	53	34	55	60	70	4.30	+1.4	13	12.6	s.	35	e.	30	11	10	10	5.3	0.0	0.0
Wichita.....	1,358	85	93	28.44	29.85	-0.05	64.6	-0.5	85	29	74	35	8	56	29	58	54	73	8.14	+3.7	20	10.8	s.	36	sw.	18	8	11	12	6.0	0.0	0.0
Oklahoma City.....	1,214	10	47	28.59	29.85	-0.04	68.8	+1.1	90	20	78	38	8	59	27	61	57	72	5.92	+1.0	10	10.3	s.	28	s.	3	2	18	11	6.5	0.0	0.0
Southern Slope							71.5	+0.9										53	2.80	+0.1										4.2		
Abilene.....	1,738	10	56	28.06	29.82	-0.05	73.6	+1.6	99	29	85	42	8	62	30	62	55	59	6.61	+2.6	9	12.0	s.	32	se.	3	13	11	7	4.7	0.0	0.0
Amarillo.....	3,676	10	49	26.16	29.82	-0.02	65.9	+1.8	94	28	79	34	8	53	36	53	43	62	4.03	+1.2	11	10.5	s.	31	w.	3	11	14	6	4.5	0.0	0.0
Del Rio.....	960	63	71	28.83	29.79	-0.06	78.1	+1.1	98	29	88	55	10	68	37	66	59	59	5.55	-2.3	7	11.7	se.	28	nw.	7	10	14	7	5.0	0.0	0.0
Roswell.....	3,666	75	85	26.26	29.80	-0.02	68.4	-1.0	101	28	84	35	10	53	45	62	39	41	0.3	-1.1	1	9.6	s.	35	ne.	30	19	10	2	2.6	0.0	0.0
Southern Plateau							65.5	+0.4										34	0.23	-0.3										3.3		
El Paso.....	3,778	82	101	24.08	29.77	-0.01	73.1	+1.6	98	27	86	48	10	60	36	51	27	22	0.2	-0.3	1	9.5	nw.	30	sw.	18	23	8	0	2.0	0.0	0.0
Albuquerque.....	4,972	5	39	24.96	29.78	-0.02	62.8	-0.5	93	28	80	30	7	46	43	45	27	33	0.2	-0.6	2	10.5	w.	42	s.	15	13	9	9	4.4	0.0	0.0
Santa Fe.....	7,013	38	53	23.20	29.83	+0.02	55.6	-1.1	83	28	69	27	7	42	36	41	27	41	0.80	-0.5	5	6.6	e.	20	n.	3	5	13	13	6.4	0.0	0.0
Flagstaff.....	6,907	10	59	23.31	29.80	+0.02	50.8	-1.1	83	26	68	15	7	34	46	38	46	38	1.13	-1.0	3	9.7	sw.	32	s.	16	8	20	3	1.0	0.0	0.0
Phoenix.....	1,107	39	51	28.66	29.79	+0.01	76.1	+1.1	108	31	92	48	3	61	40	55	36	28	0.0	-1.0	0	6.8	w.	21	nw.	6	21	8	2	2.5	0.0	0.0
Yuma.....	141	9	54	29.66	29.81	+0.02	77.4	+1.2	109	31	94	51	4	61	42	57	39	33	0.0	0.0	0	6.2	w.	34	w.	2	27	3	1	1.0	0.0	0.0
Independence.....	3,957	5	26	25.92	29.91	+0.07	62.5	-0.5	92	13	78	36	7	48	39	47	31	31	0.64	+0.5	1	1.0	n.	23	6	2	23	6	2	0.0	0.0	0.0
Middle Plateau							56.0	+0.4										52	0.92	+0.1										5.9		
Reno.....	4,529	61	76	25.46	29.96	+0.05	56.2	+2.0	87	25	70	26	3	43	38	45	34	50	0.27	-0.4	4	7.3	w.	25	w.	15	12	16	3	4.1	2.2	0.0
Tonopah.....	6,000	12	20	25.00	29.97	+0.06	54.8	-0.5	85	13	66	25	3	44	35	42	30	48	1.58	-0.2	7	9.4	nw.	32	nw.	2	12	6	13	5.0	0.0	0.0
Winnemucca.....	4,344	18	56	26.00	29.97	+0.06	54.7	-0.8	89	26	70	25	6	40	46	44	33	54	0.80	-1.1	8	7.3	sw.	31	se.	14	5	16	10	5.9	0.0	0.0
Modena.....	5,473	10	43	24.56	29.89	+0.04	53.2	-0.3	88	14	69	22	7	38	43	42	31	53	1.82	+1.0	7	9.8	w.	35	s.	18	12	10	9	5.0	4.6	0.0
Salt Lake City.....	4,227	32	46	25.68	29.90	+0.04	55.2	-0.1	87	26	68	29	7	43	38	45	36	56	2.04	-0.2	11	8.8	se.	33	nw.	4	7	12	12	5.9	0.0	0.0
Grand Junction.....	4,602	60	68	25.29	29.83	0.00	60.1	-1.0	91	27	73	35	7	48	35	47	35	48	0.81	0.0	8	7.1	n.	42	sw.	15	7	13	11	5.5	0.0	0.0
Northern Plateau							56.6	+0.5										51	1.20	-0.2										5.6		
Baker.....	3,471	36	54	26.46	30.02	+0.06	52.0	+0.3	85	25	66	26	3	38	40	43	35	60	0.83	-1.0	4	6.6	n.	28	n.	17	9	8	14	6.3	0.0	0.0
Boise.....	2,739	79	87	27.14	29.99	+0.05	56.2	-0.9	89	26	68	31	6	44	35	46	37	55	2.55	+1.1	8	5.6	nw.	26	nw.	17	8	11	12	5.5	0.0	0.0
Pocatello.....	4,477	60	68	25.43	29.93	+0.04	53.0	-0.8	83	27	65	28	6	41	37	43	34	55	1.64	+1.1	15	8.6	w.	30	sw.	18	4	14	13	6.8	5.8	0.0
Spokane.....	1,929	101	110	27.94	29.98	+0.02	56.8	+1.3	87	26	69	34	5	45	35	46	35	51	0.47	-1.0	7	7.6	s.	27	sw.	12	9	12	10	5.4	0.0	0.0
Walla Walla.....	991	57	65	28.94	30.01	+0.05	60.6	+1.0	91	25	72	40	2	49	31	49	37	46	1.84	+2.8	8	6.6	s.	25	e.	27	12	10	9	4.8	0.0	0.0
Yakima.....	1,076	58	67	28.86	30.00	0.00	61.1	+2.1	94	25	74	35	4	48	37	48	34	41	0.19	-0.4	3	7.6	nw.	28	w.	12	12	10	9	4.8	0.0	0.0
North Pacific Coast Region							56.1	+1.8										68	1.05	-1.3										5.4		
North Head.....	211	11	56	29.91	30.14	+0.11	50.6	-0.3	63	20	54	41	2	47	13	48	46	86	1.98	-1.0	9	15.7	nw.	47	s.	3	9	6	16	6.1	0.0	0.0
Seattle.....	125	90	321	29.94	30.07	+0.06	57.8	+3.3	83	21	67	42	2	48	32	50	42	62	1.04	-0.8	7	9.1	n.	32	sw.	12	12	6	13	5.1	0.0	0.0
Tacoma.....	194	172	201	29.89	30.09	+0.07	56.4	+2.3	80	21	65	41	2	48	28	42	42	62	0.70	-1.4	8	9.1	n.	29	sw.	12	11	13	7	4.7	0.0	0.0
Tatoosh Island.....	86	10	54	30.01	30.11	+0.10	49.8	-0.2	66	19	54	40	3	46	18	47	44	81	2.55	-1.4	12	10.7	sw.	41	w.	17	11	7	13	5.5	0.0	0.0
Medford.....	1,329	29	58	28.65	30.06	+0.09	50.9	+2.2	92	25	75	33	18	44	43	49	40	58	2.33	-1.0	3	10.0	nw.	24	n.	9	10	12	5.3	0.0	0.0	
Portland, Oreg.....	154	68	106	29.93	30.09	+0.06	59.4	+2.5	89	23	70	40	6	49	32	51	43	59	0.65	-1.5												

TABLE 3.—Data furnished by the Canadian Meteorological Service, May 1938

Station	Altitude above mean sea level, Jan. 1, 1919	Pressure			Temperature of the air						Precipitation		
		Station reduced to mean of 24 hours	Sea level reduced to mean of 24 hours	Depart- ure from normal	Mean max. + mean min. +2	Depart- ure from normal	Mean maxi- mum	Mean mini- mum	Highest	Lowest	Total	Depart- ure from normal	Total snowfall
	Feet	In.	In.	In.	°F.	°F.	°F.	°F.	°F.	°F.	In.	In.	In.
Cape Race, Newfoundland.....	99				38.1	-1.9	43.9	32.3	56	27	4.66	+0.30	T
Sydney, Cape Breton Island.....	48	29.83	29.89	-0.08	46.3	+1.1	50.4	36.2	74	29	2.51	- .94	0.6
Halifax, Nova Scotia.....	88	29.65	29.92	- .05	48.3	-1.0	55.4	41.2	72	33	3.68	- .49	.0
Yarmouth, Nova Scotia.....	65	29.82	29.93	- .04	48.2	+ .2	55.7	40.7	67	33	2.71	- .84	.0
Charlottetown, Prince Edward Island.....	38	29.81	29.89	- .06	48.2	+ .4	56.5	39.9	72	32	2.71	+ .14	T
Chatham, New Brunswick.....	28	29.78	29.89	- .06	47.7	-1.7	58.4	37.0	83	27	3.61	+ .41	.0
Father Point, Quebec.....	20	29.87	29.89	- .03	45.8	+1.4	52.5	39.2	73	31	1.95	- .88	.0
Quebec, Quebec.....	296												
Doucet, Quebec.....	1,236				47.5	+3.7	61.6	33.5	78	22	1.34	-1.57	.0
Montreal, Quebec.....	187												
Ottawa, Ontario.....	236	29.64	29.89	- .03	54.1	-1.5	64.9	43.5	78	34	2.94	+ .26	.0
Kingston, Ontario.....	285	29.62	29.92	- .03	54.7	+1.4	63.0	46.5	77	36	1.10	-1.84	.0
Toronto, Ontario.....	379	29.52	29.94	- .03	55.2	+ .9	63.9	46.4	78	36	2.15	- .77	T
Cochrane, Ontario.....	930				49.3	+2.8	61.3	37.4	79	28	1.90	- .32	3.8
White River, Ontario.....	1,244	28.62	29.96	.00	49.8	+2.4	62.9	36.6	77	20	1.46	- .74	.2
London, Ontario.....	808				54.2	-1.6	64.5	43.9	80	29	3.99	+ .73	T
Southampton, Ontario.....	656	29.24	29.94	- .02	51.2	+ .3	60.5	42.0	80	32	3.34	+ .73	.0
Parry Sound, Ontario.....	688	29.26	29.96	.00	53.8	+1.8	64.1	43.4	84	33	2.58	- .35	T
Port Arthur, Ontario.....	644	29.26	29.96	- .01	47.2	+ .2	55.2	39.2	72	26	2.56	+ .46	.0
Winnipeg, Manitoba.....	760												
Minneapolis, Manitoba.....	1,690	28.12	29.94	.00	49.5	- .3	61.5	37.6	78	24	1.12	- .66	T
Le Pas, Manitoba.....	860												
Qu'Appelle, Saskatchewan.....	2,115	27.64	29.92	- .01	49.4	- .8	60.5	38.3	83	24	2.01	- .09	.1
Moose Jaw, Saskatchewan.....	1,759				51.6	+ .3	62.6	40.7	88	27	2.40	+ .42	T
Swift Current, Saskatchewan.....	2,392	27.36	29.94	+ .02	50.9	- .4	61.4	40.4	89	27	2.12	+ .21	T
Medicine Hat, Alberta.....	2,365	27.44	29.92	+ .04	53.2	-2.0	63.6	42.8	86	29	2.35	+ .73	.4
Calgary, Alberta.....	3,540	28.30	29.98	+ .06	49.0	+ .1	59.7	38.4	78	26	3.44	+1.27	1.6
Banff, Alberta.....	4,521												
Prince Albert, Saskatchewan.....	1,450	28.43	29.98	+ .03	50.8	+1.0	61.7	39.8	89	24	1.32	- .11	.6
Battleford, Saskatchewan.....	1,592	28.20	29.92	.00	50.7	+1.3	64.3	37.1	87	25	1.76	+ .14	.1
Edmonton, Alberta.....	2,150	27.66	29.94	+ .06	51.1	.0	63.8	38.4	82	25	1.43	- .28	1.6
Kamloops, British Columbia.....	1,262	28.68	30.04	+ .11	59.6	+1.9	72.9	46.2	91	34	.35	- .56	.0
Victoria, British Columbia.....	230	29.85	30.11	+ .08	53.0	.0	60.1	46.0	73	39	.54	- .55	T
Barkerville, British Columbia.....	4,180												
Estevan Point, British Columbia.....	20				50.0	+ .8	55.4	44.5	65	38	5.33	- .03	.0
Prince Rupert, British Columbia.....	170				48.6	+ .3	55.6	41.5	72	34	4.20	-1.12	.0
St. George's Bermuda.....	158		30.06	.00	72.8	+3.7	78.0	67.6	84	64	6.31	+2.11	.0

LATE REPORTS FOR APRIL 1938

Cape Race, Newfoundland.....	99				32.2	-0.6	37.3	27.1	46	16	7.28	+3.19	13.2
Le Pas, Manitoba.....	860				31.6	-1.4	43.7	19.4	75	-12	.36	- .34	3.6

TABLE 4.—Severe local storms, May 1938

[Compiled by Mary O. Souder from reports submitted by Weather Bureau officials]

[The table herewith contains such data as have been received concerning severe local storms that occurred during the month. A revised list of tornadoes will appear in the United States Meteorological Yearbook]

Place	Date	Time	Width of path, yards	Loss of life	Value of property destroyed	Character of storm	Remarks
Russell, Minn., and vicinity	1	3:45 p. m.			\$5,000	Thundersquall and hail.	Roof of high school torn away; several small buildings wrecked; greenhouse damaged; number of telephone and power lines down; some damage to newly seeded fields.
Clark County, Kans., south-eastern portion.	1	4 p. m.	115		10,000	Heavy hail.	Damage mostly to crops; path 25 miles long.
Protection and Coldwater, Kans., and vicinity.	1	5:45 p. m.	880	0	35,000	Tornado.	Storm moved from the southwest; 1 person injured; many farm buildings damaged.
Sun City and Isabel, Kans., and vicinity.	1	7:30-8 p. m.	1	0	10,000	Tornado and hail.	Storm moved from the southwest; 50 percent loss to wheat crop by hail; path 25 miles long.
Arlington, Kans., vicinity of.	1	9:30 p. m.	880	0	12,000	Tornado.	Storm moved from the southwest; 2 persons injured; path 2 1/4 miles long.
Cunningham, Kans., vicinity of.	1	9:30-10 p. m.	200	6	100,000	do.	Storm moved from the southwest; 20 persons injured; all buildings on 1 farm completely blown away; many other farm buildings struck; path 13 miles long.
Pennington, Wis.	2	P. m.			500	Heavy hail.	Windows broken; roofs and automobile tops damaged.
Rockford and Charles City, Iowa, vicinity of.	2				600	Wind.	Barn moved 20 feet; cow killed; chicken house demolished.
Minnesota southwestern central and southeastern portions.	3	2-7:15 p. m.		1	185,400	Thundersquall.	Number of farm buildings demolished and others damaged; poles and wires down; trees uprooted; 2 persons injured; some livestock and poultry perished.
Norton, Kans., 4 miles south-east.	3	5 p. m.		0		Tornado.	Storm lasted about a minute; no damage reported.
Hardin and Franklin Counties, Iowa.	3	5:10 p. m.			500	Hail.	Windows and glass in greenhouse broken; fruit trees damaged.
Argonia, Kans., vicinity of.	3	5:15 p. m.	440	0	10,000	do.	3 whirling clouds seen; several barns and outbuildings demolished; loss to crops, \$1,000; storm moved from the southwest over a path 9 miles long.
Crowell County, Tex.	3	6 p. m.			100,000	Heavy hail.	Loss to crops, \$100,000; property damage not estimated.
Marquette, Wis.	3	P. m.				Heavy rain, electrical and hail.	1.76 inches of rain in an hour recorded. Basements and streets flooded; motors stalled on highways; much damage to newly seeded gardens.
Antigo, Wis., vicinity of.	3		33	0	10,000	Tornado.	2 women injured by debris; 4 barns demolished and a house damaged; other minor damage.
La Crosse, Wis.	3				25,000	Thundersquall.	1 person injured; buildings and power lines damaged. Storm covered an area of 30 square miles.
Neva, Wis., vicinity of.	3				900	Hail.	Area of 4 square miles affected. Some hailstones as large as hen eggs.
Sedgwick County, Kans.	4	1 a. m.			6,000	Wind.	Damage in Wichita, \$5,000. Residence demolished; small outbuildings moved from their foundations; wires down.
Allen County, Kans.	4	8:30 a. m.	100	0	1,000	Tornado.	Storm moving from the south originated 4 miles west of Moran. Farm-house damaged; several farm buildings demolished; path a mile long.
La Harpe, Iowa, and Colony, Kans.	4	9 a. m.			4,500	Wind.	Several farm buildings destroyed or badly damaged. Path from 300 yards to 3 miles wide and from 7 to 25 miles long.
Franklin County, Kans., eastern portion.	4	9:30 a. m.			1,000	do.	Damage to farm property.
Olathe, Kans., vicinity of.	4	9:55 a. m.	50	0	200	Tornado.	Slight damage to a residence and to power lines. Path of storm east southeast over a path 440 yards long.
Warsaw, Mo.	4	11 a. m.		0	2,000-3,000	Tornado, rain, and hail.	Property damaged.
Cameron, Mo., vicinity of.	4	A. m.			1,000	Tornado.	Damage to buildings, roofs, and trees.
Eudora, Kans., 2 miles south-east.	4	3 p. m.		0	1,000	do.	Path short and not well-defined.
Jefferson and Waukesha Counties, Wis.	4	7:30-8 p. m.	110		4,000	Wind.	Property damaged; path 10 miles long.
Rosendale and Byron, Wis.	4	8 p. m.	125		2,000	Thundersqualls.	Property damaged; path 25 miles long.
Lowell, Wis., vicinity of.	4	10 p. m.	115		1,000	Thundersquall.	Property damaged; path 15 miles long.
Aitkin County, Minn.	4	P. m.			12,100	Rain and flood.	Heavy rains caused much damage, mainly to highways.
Wabasha County, Minn.	4	do.				do.	Heavy and excessive rains in the lower Zumbro and Whitewater River valleys resulting in the overflowing of streams and the flooding of lowlands.
Cambridge, Cameron, Galva, Monmouth, Sciota, Swan Creek, and Woodhull, Ill.	4				13,300	Wind.	Property damaged.
Ludlow-Chula, Mo., and vicinity.	4			0	10,000	Tornado.	Buildings, roofs, and trees damaged; outbuildings wrecked.
Chillicothe, Tex., vicinity of.	4		15			Heavy hail.	Crop loss, 50 percent, amount not estimated; path 20 miles long.
Vernon, Tex.	4		14		100,000	do.	\$100,000 loss to crops; damage to roofs, trees, and shrubs not estimated.
Houston, Tex.	6	1-11:30 p. m.				Wind.	High winds caused much damage to roofs, electric wires, and trees; amount of damage not estimated.
Barker-Fairbanks, Tex.	6	1:30 p. m.	110	0	4,000	Tornado and hail.	Damage from hail not estimated; no details.
Coffeyville and Angola, Kans., and vicinity.	6	5-6 p. m.	13		55,000	Heavy hail.	Loss to crops, \$30,000; property damage, \$25,000. Storm moved from the southwest over a path 13 miles long.
Irving, Tex.	6	5:15 p. m.	13		4,000	Wind.	No details.
Coffeyville, Kans.	6	5:30 p. m.		0	100	Tornado.	Several small buildings destroyed. Storm moved from the southwest over a narrow path 100 yards long.
Duncanville, Tex.	6	6 p. m.	12	0	70,000	Heavy hail and wind.	Loss to crops, \$70,000; additional damage to small buildings not estimated; path 10 miles long.
Oklahoma City, Okla.	6	P. m.			1,000	Hail.	Fall of hail unusually heavy; stones small.
Chicago, Ill., and vicinity.	6			1		Wind.	8 children injured.
Lawton, Okla.	6				100,000	Wind and hail.	Property damaged.
New Orleans, La.	7	3:29 a. m.				Wind.	Gust velocity of 43 miles per hour at Shushan Airport. Trees blown down; damage to electric power lines in downtown sections of the city.
Boone County, Ark.	7	4-4:30 a. m.	440	0	9,500	Tornado.	Buildings damaged or destroyed; trees uprooted. Storm moved toward the east over a path 15 miles long.
Alamance County, N. C., northern portion.	7	7 p. m.			2,500	Wind.	Property damaged.
Minnesota, north-central counties.	8				33,100	Flood.	Following an extended period of heavy rain, streams overflowed their banks; highways and lowlands inundated and several bridges washed out.
Sugar Loaf Key, Fla.	10	1:40 p. m.	100	0	250	Tornado.	At Pirates' Cove Fishing Camp, about 23 miles east-northeast of Key West. Damage to storm shutters, screens, and a small shed. Path 1 mile long.
Clay and Geary Counties, Kans.	10	3-4:30 p. m.	12		10,000	Heavy hail.	In some places, ground was covered 4 to 6 inches with hail. Property damage in Clay Center, \$1,000. Chief damage to wheat; path 2 miles long.
Ness City, Kans., vicinity of.	11	4 p. m.	12-4		10,000	do.	Loss to crops; path 8 miles long.
Haskell, Tex.	11	5 p. m.	16		40,000	do.	Amount estimated loss to crops only; some damage to roofs; path 7 miles long.

See footnotes at end of table.

TABLE 4.—Severe local storms, May 1938—Continued

Place	Date	Time	Width of path, yards	Loss of life	Value of property destroyed	Character of storm	Remarks
Spearville, Kans., vicinity of...	11	6 p. m.	1		\$10,000	Heavy hail	Loss mostly to crops. Storm moved from the northeast over a path 5 miles long.
Emporia to Neosho Rapids, Kans.	11	7 p. m.	1 2 1/4		140,000	do.	Loss to wheat and other crops; path 35 miles long.
Bunker Hill, Kans.	11	7:30 p. m.	1 2			do.	Loss to wheat crop, 75 percent; path 10 miles long.
Greensburg, Kans.	11	7:30-9 p. m.	1 3-4		7,500	do.	Loss to crops; storm moved from the northwest over a path 8 miles long.
Bavaria, Kans., vicinity of...	11	8 p. m.	1 2		12,000	do.	Loss to wheat crop; path 6 miles long.
Chase County, Kans.	11	do.	1 8		5,000	do.	Loss to wheat; path 12 miles long.
Yates Center, Kans., vicinity of...	11	8:15 p. m.	1 3-7		67,000	do.	Crop loss, \$60,000; property damage, \$7,000; path 14 miles long.
Kipp to Gypsum, Kans., vicinity of...	11	8:30-9 p. m.	1 1		3,000	do.	Loss to wheat in some places 70 percent; path 8 miles long.
Hardy, Nebr., to vicinity of Clyde, Kans.	11	9:15-9:30 p. m.	1 2-4		100,000	do.	Loss of 20,000 acres of crops. In Belleville, Kans., hail fell to the depth of a foot, in spots, with \$15,000 property damage. Path 40 miles long.
Ellsworth County, Kans.	11	10 p. m. mid-night.	1 12		1,000	do.	Loss to crops; path 15 miles long.
Nuckolls, Dawson, and Gosper Counties, Nebr.	11	P. m.		0	85,000	Tornado	Property damaged.
Weinert, Tex.	12	4 p. m.	1 4		25,000	Heavy hail	Loss to crops; path 12 miles long.
Anson, Tex.	12	7 p. m.	1 7		21,500	Heavy hail and wind.	Loss to crops by hail, \$20,000; damage to roofs by wind, \$1,500; path 10 miles long.
Stamford to Tuxedo, Tex.	13	5:30 p. m.	1 5		120,000	Heavy hail	Loss to crops; additional small damage to roofs; path 10 miles long.
Hico, Tex.	13	P. m.	1 2		5,000	do.	Much damage to gardens.
Beckley, W. Va.	14	2 p. m.			4,000	Wind and rain	Roof of hangar lifted from its base and moved 10 feet; an airplane damaged; circus tent blown down.
Richmond, Va.	14	7:30 p. m.			5,000	Thundersquall	Trees uprooted; property damaged.
Vanderburg County, Ind.	14				2,000	Wind.	No details.
Nashville, Tenn.	14-15					Dust.	On the 14th visibility reduced to 4 miles. Storm persisted until the afternoon of the 15th.
Sinton, Tex., vicinity of...	16			1		Tornado and rain.	Many houses and barns destroyed. Rainfall in this vicinity averaged from 2 to 12 inches.
Southern Bee, western Refugio and northern San Patricio Counties, Tex.	16				4,500,000	Straight-line wind.	Small tornado noted near Sinton, but damage given caused by wind.
Bolivar and Coahoma Counties, Miss.	17	3 p. m.	100		25,000	Tornado winds	Storm moved southwest to northeast and crossed about midway of the line of Bolivar-Coahoma Counties. 12 persons injured; property damaged; path 12 miles long.
Boise, Idaho	17	5:50-6:22 p. m.				Squall	Trees uprooted; electric service interrupted.
Kingsbury County, S. Dak.	17	P. m.				Heavy rain	About 60 feet of track-Xkage and a 7-foot culvert of the Great Northern Railroad, 5 miles northeast of Bancroft, washed out. Fences on farms damaged and poultry drowned.
Hastings and Jordan, Minn.	17-18				157,135	Rain and flood	Heavy to excessive rains washed out 200 feet of railroad track, 3 miles north of Hastings; also stretches of track in the vicinity of Inver Grove, Jordan, Belle Plaine, and Granite Falls. Basements, streets, and highways flooded. Many acres of lowlands under water. Section of Highland Park stadium bleachers washed out at St. Paul.
River Falls, Wis., and vicinities.	17-18				100,000	Heavy rain	Many bridges washed out. \$100,000 damage to the Burlington Railroad from Prescott to St. Croix Falls. About 1 1/4 miles east of Prescott a railroad bridge and 400 feet of roadbed washed out. Highways in St. Croix, Pepin, and Dunn Counties inundated.
Montana, central and southern portions.	17-21					Heavy snow	Wet snow up to 4 feet reported. Thousands of dollars damage to forest timber as well as shade trees in many towns and cities. In some higher forested areas, as much as 10 percent of standing timber down. High mountain passes blocked from several hours to 2 days. Rock slides and fallen timber added to the difficulty of clearing highways. Fruit trees considerably damaged in the Bitterroot Valley and much of the winter wheat crop badly flattened in the Gallatin Valley. Plane and rail service affected. Communication and power-line service interrupted with thousands of dollars' damage. In Anaconda the weight of the heavy snow crushed the walls of a garage, burying 3 automobiles. Warm Springs heavy loss of game birds occurred when pens collapsed at the State Game Farm.
Anthony, Kans., 8 miles northwest.	18	3 p. m.	100	0	1,500	Tornado	Damage to farm buildings; 1 person injured; path 440 yards long.
Sedgewick County, Kans.	18	4-7 p. m.			11,500	Wind	Damage in Wichita, \$10,000; in the southern portion of the county, \$1,500.
Delaware, Dubuque, and Jackson Counties, Iowa.	18	P. m.		0	7,000	Tornado	Storm moved from west to east wrecking all buildings on 1 farm and damaging buildings on 3 others in Dubuque and Jackson Counties.
Grand Rapids, Mich.	19	2:56 a. m.-10 p. m.				Heavy rainfall, electrical.	2.88 inches of rain recorded. Street flooded with several inches of water. All emergency crews at work to keep power and light on. Washouts and inundated highways reported by the Michigan State Highway Department, making it necessary to detour traffic.
Calpeper County, Va.	19	1:30 p. m.	900	0	2,000	Tornado	Storm moved from southwest to northeast. Property damaged over a path 5 miles long.
Milwaukee, Wis., and vicinity.	19	5-6 p. m.				Heavy rain, electrical.	1.10 inches of rain recorded during this storm. Streets flooded with 2 feet of water; sewers inadequate; traffic disrupted; scores of motors stalled. Lightning struck 2 electric power wires in the northwestern part of Milwaukee County disrupting service over a wide area. Many highways in Eau Claire, Dunn, Pepin, Pierce, and St. Croix Counties impassable due to bridges and culverts being washed out or inundated by flood waters from swollen streams.
Chicago, Ill.	19				15,000	Thundersquall	Apartment house damaged by fire; church steeple struck; trees blown down in many sections of the city.
La Porte and Allen Counties, Ind.	19				23,000	Wind	No details.
Rock Island, Ill.	19				1,000	do.	Property damaged.
Xenia, Ill.	19					do.	Damage to fruit trees.
Detroit, Mich.	19			1		Thunderstorm	Considerable damage to wires. Woman killed by stepping on a high-tension wire. During the heavy rain visibility was reduced to zero making it impossible for traffic to move. Street flooded from curb to curb for several hours after the storm.
Richmond County, Va., lower portion.	20	3:30 p. m.	900	3	5,000	Tornado	Storm moved from west-southwest to east-northeast. 2 persons injured; property damaged over a path 30 miles long.
Idalia, Colo.	20	6 p. m.	1 10-15		25,000	Heavy hail	Small grain crops and gardens almost completely destroyed.
Jones County, N. C.	20	6:30 p. m.			3,000	Wind	Barns damaged.
Pike County, Ind.	20				15,000	do.	No details.
Sherman, Cheyenne, Thomas, Rawlins, Decatur, and Norton Counties, Kans.	20-21	7 p. m.-1 a. m.	1 8-12		500,000	Heavy hail	Storm originated in Colorado; path 130 miles long extending from the State line to Phillips County. Principal loss to wheat crop.
Gallipolis, Ohio, vicinity of...	21	2 p. m.	800		1,500	do.	Loss to crops.
Clinton, Green, and Montgomery Counties, Ohio.	21	2-5 p. m.	1 3			do.	Gardens damaged, windows broken.
Clay and Riley Counties, Kans.	21	3:30 a. m.	1 3-6		100,000	do.	Chief loss to wheat which was completely destroyed in spots. Property damage in Clay Center, \$25,000. Path 35 miles long.

See footnotes at end of table.

TABLE 4.—Severe local storms, May 1938—Continued

Place	Date	Time	Width of path, yards	Loss of life	Value of property destroyed	Character of storm	Remarks
Hawley, Tex.	21	6:30 a. m.	175	0	\$2,300	Tornado	\$2,000 damage to an oil rig and buildings; \$300 crop loss; path 5 miles long.
Sumter, S. C.	21	8 p. m.	35	0	500	do.	Roofs of 8 dry kilns at Sumter Brick Works blown off; dwelling and barn, nearby, damaged. Storm moved from the northwest over a path 880 yards long.
New Burnside, Ill.	21				1,000	Electrical	Barn and contents burned.
Palestine, Ill.	21				2,000	Wind	Damage to roofs, silos, and windows.
Evansville, Ind.	21					Thunderstorm and hail	Growing crops damaged by rain and hail. Sewers inadequate; interconnections flooded.
Grant, Green, Monroe, Knox, and Owen Counties, Ind.	21			0	272,000	Tornadoes	No details.
Ivan, Tex.	22	3 p. m.	250	4	7,000	Tornado	10 persons injured; crop loss, \$7,000; small damage to buildings not estimated.
Ada and Duncan, Okla., and vicinity. ¹	22	6 p. m.		0	100,000	Tornadoes and rain	4 persons injured; 6 homes in Ada demolished and over 20 others unroofed. Porches and outbuildings wrecked and trees down. Roofs blown off in Duncan.
Comanche County, Tex.	22	do.		0	25,000	Tornado	Property damaged.
Waldron, Ark., 2 miles north.	22	10 p. m.	50	0	1,100	do.	Houses and barns destroyed or unroofed. Storm moved north-northeast over a path 1½ miles long.
Yell County, Ark.	22	10:35-11 p. m.	440-880	0	12,000	do.	10 persons injured; 3 houses destroyed; other property damaged; path 40 miles long.
Pope and Conway Counties, Ark.	22	11 p. m.-Midnight	150-440	2	20,000	do.	10 persons injured; a church, 7 residences, several barns, a cotton storehouse, a seed house, and 2 gin houses destroyed.
Cleburne and Van Buren Counties, Ark.	22	P. m.			1,000	Wind	Several outbuildings blown down.
Washington County, Ark.	22				5,000	Heavy rain	Roads and bridges damaged.
Person County, N. C.	23	3 p. m.			1,000	Wind	Roofs blown off of 4 small buildings.
Muskingum and Morgan Counties, Ohio.	23	do.	15			Heavy hail	Heavy damage to crops, windows, roofs, and automobile tops; path 10 miles long.
St. Matthews, S. C.	23	3:30 p. m.		0	5,000	Tornado	Hotel roof blown off; trees blown down; telephone and electric service disrupted; windows broken and residences damaged. Storm moved from the southwest.
Green, Fayette, Washington, Allegheny, and Westmoreland Counties, Pa.	23	5-9 p. m.		0	75,000	Heavy hail and wind	Hail 6 inches deep in eastern Green County. Loss chiefly to crops.
Orangeburg, S. C.	23	5:20 p. m.	440-880	0	2,000	Tornado	Storm moved from the southwest over a path 15 miles long; property damaged.
Salem Township, Pa.	23	6 p. m.	75	0	8,000	do.	Damage chiefly to small buildings; loss to crops small.
Richmond, Va.	23	8:30 p. m.			3,000	Thundersquall	Property damaged.
Alfarata, McClure, and Beaver Springs, Pa.	23	9 p. m.	1		200,000	Wind, hail, electrical	Most serious damage at Alfarata, with 40 houses unroofed throughout the area. Much damage in McClure and Beaver Springs. Hundreds of fruit trees destroyed near McClure. Some evidence of tornado action at Alfarata.
Aurora, Ind., ¹ and vicinity	23	P. m.				Rain	The Ohio River overflowed; much bottom land inundated; loss to corn crop.
Maysville, S. C.	23	do.		0	2,000	Tornado	A 2-story school wrecked; several houses damaged.
Pendleton, S. C.	23	Midnight			5,000	Electrical	Church destroyed.
Thompsonville, Ill.	23				5,000	Wind	Property damaged.
Bowling Green, Ind. ¹	23					do.	Trees uprooted; chimneys blown down; roofs damaged; no electric service for several hours. Large tree blown into Eel River carried the flood crest to State Road 42, west of Poland, where supports from a temporary bridge were torn away, delaying traffic for several days.
Vincennes, Ind., ¹ and vicinity	23					Wind and rain	Storm most severe experienced in recent years. Section of a brick wall blown over injuring 3 persons. Large trees uprooted blocking motor and streetcar traffic; utility lines blown down. Loss to peach and apple crops.
Buffalo, N. Y.	23			1		Gale	Outside the harbor in Lake Erie, a tug capsized and the captain drowned. Some rowboats and sailboats torn loose from their moorings.
Nash County, N. C., eastern portion.	23				5,000	Wind	Damage to barns and outbuildings.
Giles and Marshall Counties, Tenn.	23				20,000	Hailstorm	Crop loss, \$20,000; property damage not estimated.
Robertson and Dickson Counties, Tenn.	23					Rain and hail	Loss to gardens, grain and tobacco plants.
Norfolk, Va.	24	2:50-7:50 p. m.			2,000	Thunderstorm	Property damaged.
Ionia, Kans., vicinity of.	24	4 p. m.	1		5,000	Heavy hail	Path 4 miles long; no details.
Wessington Springs, S. Dak., vicinity of.	24	5 p. m.			1,000	Hail	Loss to rye crop.
Phillipsburg, Kans., 12 miles northwest.	24	6 p. m.	12		12,000	Heavy hail	Loss to crops; path 3 miles long.
Lincoln and Ellsworth Counties, Kans.	24	8:30 p. m.	115		175,000	do.	Storm covered west-central part of Lincoln County and northern portion of Ellsworth County; much wheat total loss; path 15 miles long.
Russell, Kans., 8 miles west.	24	6:30 p. m.	11			do.	Total loss to wheat over an area 1 mile wide and 2 miles long. Path 4 miles long. Damage not estimated.
McFarland, Kans., and vicinity.	26	6 p. m.	13		30,000	do.	Much wheat total loss; path 5 miles long.
Lincoln County, Kans.	26	9-10 p. m.	16		75,000	do.	Loss to wheat crop; path 12 miles long.
Mineola, Kans., vicinity of.	26	10 p. m.	11		20,000	do.	Loss to wheat, path 5 miles long.
Milton to Youngsville, La.	26-27	P. m.				do.	About 300 acres of cotton and 300 acres of corn total loss.
Inwood, Iowa, 10 miles east.	26					Heavy rain and hail	Fields washed; gardens ruined; trees stripped; loss in grain.
Carnegie, Okla., ¹ vicinity of.	26		14		30,000	Rain and hail	Wheat crop total loss.
Edinburg, Tex., vicinity of.	27	4 p. m.	12		50,000	Heavy hail	Loss to crops; path 5 miles long.
Honey Grove, Tex.	27	6 p. m.			150,000	do.	Loss to crops.
Sivells Bend, Tex.	27	7 p. m.	11½			do.	Loss to crops, accurate estimate unobtainable.
Iola, Ill.	27		12		3,000	Hail	Damage to roofs, windows, gardens, fruits, and early corn. Path 4 miles long.
Pocahontas, Mitchell, Floyd, Marshall, Tama, and Dubuque Counties, Iowa.	27					Heavy rain	Fields flooded; fences and highways damaged over scattered areas. At Osage, in Mitchell County, 4.85 inches of rain fell with damage over an area 10 miles square. At Tama 4 inches of rain fell in an hour with water waist deep in some streets. Streets flooded in Dubuque; retaining wall wrecked; pavements and sewers damaged by 1.90 inches of rain in 25 minutes. Damage to tangible property several thousand dollars. Erosion damage very large. Replanting of corn necessary; small grain total loss.
Maumee, Ohio	28	7:20 p. m.				Heavy hail and wind	Hail destroyed gardens; trees badly damaged by wind.
Stamford, Ark., vicinity of.	28	7:30 p. m.	400	0	4,000	Tornado	5 houses and 2 barns destroyed; several farm animals killed; storm moved southeastward over a short path.
Evansville, Ind., and vicinity	28				3,000	Thunderstorm and hail	Streets flooded; traffic delayed; electric service interrupted. Hail reported north of Evansville and along the Wabash in Posey County it was reliably reported that residents gathered hailstones and made ice-cream with them.

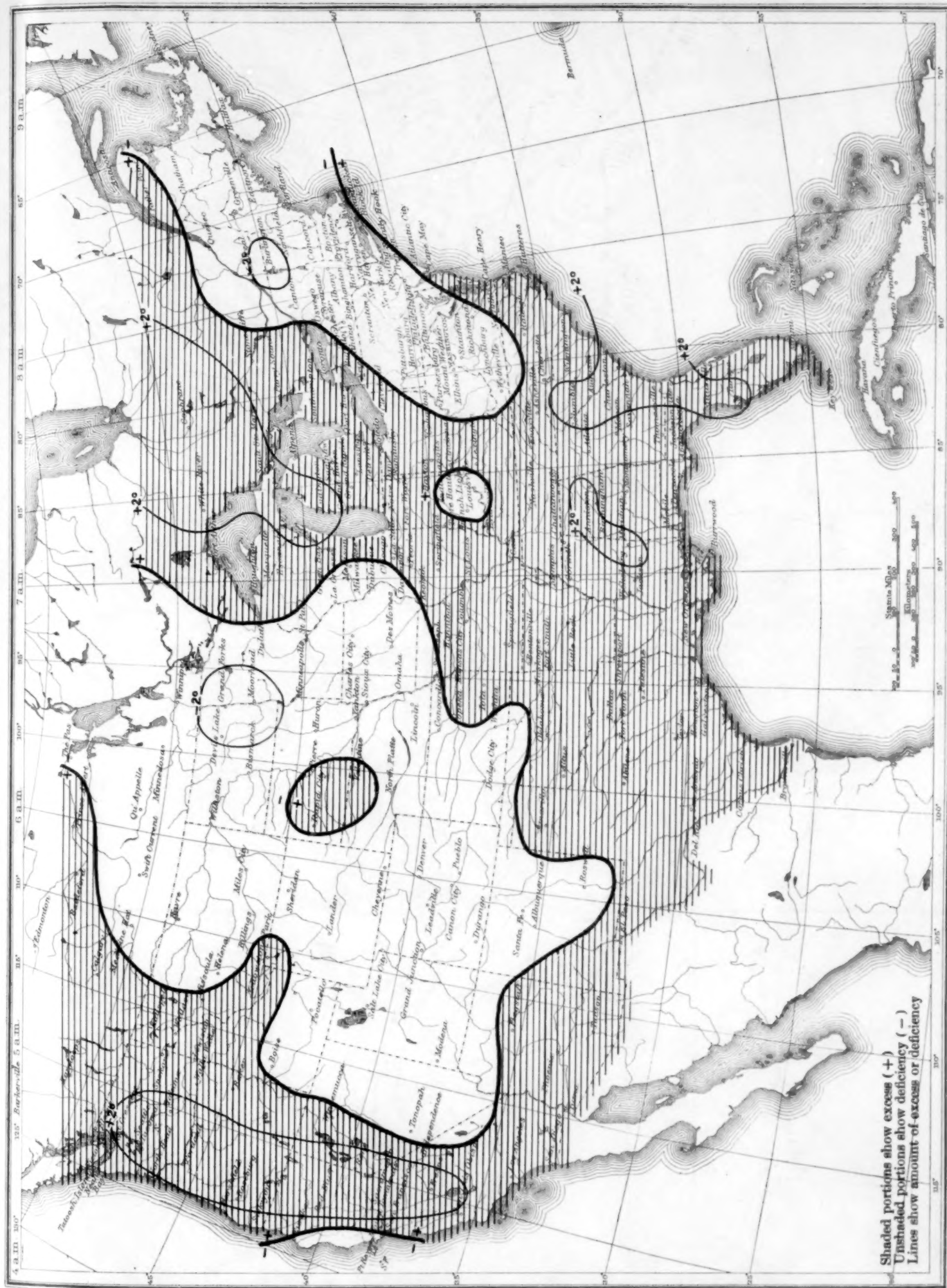
See footnotes at end of table.

TABLE 4.—Severe local storms, May 1938—Continued

Place	Date	Time	Width of path, yards	Loss of life	Value of property destroyed	Character of storm	Remarks
Jackson, Kalamazoo, and Ceresco, Mich.	28					Thundersquall	1.5 inches of rain recorded in 30 minutes caused heavy damage and plunged this industrial center into partial darkness. 2 persons injured in motor accidents attributed to the storm.
Cherokee County, Kans.	28-29	P. m.	11		\$100,000	Wind and hail	Principal loss to crops; many roofs and automobiles damaged; path 15 miles long.
Eureka Springs, Ark., and vicinity.	29	1-4 a. m.	15		1,000,000	Heavy rain and hail	Roofs, automobile tops, and crops damaged by hail; many buildings damaged by water. 12 railroad trestles and 6 miles of track of the Missouri and Arkansas Railroad washed out between Eureka Springs and Beaver with \$400,000 damage. Crop loss, \$100,000; property damage, \$500,000.
Arriba, Colo.	29	5:30 p. m.	50-100	0	25,000	Tornado	A service station, garage, 6 residences, and a church demolished. Shed of a lumber yard unroofed and 40 other buildings demolished.
Cassville, Mo.	29	Midnight				Cloudburst	Approximately 200 holiday campers narrowly escaped drowning when a cloudburst broke a fish hatchery dam and sent water up to 10 feet deep rolling over the campsites in Roaring River State Park. About 40 automobiles submerged in the flood and many washed down stream. Thousands of dollars' loss in personal effects and camp equipment. About 60,000 trout lost with the hatchery dam. More than a dozen persons spent from 2 to 4 hours perched in trees, several holding small children in their arms.
Auburn and Skaneateles, N. Y.	29					Wind and rain	Considerable damage reported from the heavy rain. Streets flooded and gardens damaged.
Gove and Trego Counties, Kans.	29-30	P. m.	14-6		150,000	Heavy hail	Loss chiefly to wheat, in some places a total loss; path 40 miles long.
Lane County, Kans., northern portion.	30	5 a. m.	18		150,000	do.	Loss in 100,000 acres of wheat; path 30 miles long.
Roy, N. Mex.	30	9 a. m.	14		10,000	Hail	Wheat crop damaged; fruit knocked from trees; poultry killed.
Tucumcari, N. Mex.	30	9:30 a. m.	12½		1,000	do.	Windows broken; roofs damaged.
Frontenac, Cornell, and Pittsburg, Kans.	30	6 p. m.				Wind	Property damaged; trees and power lines down; loss not estimated.
Ellis County, Kans.	30	6:30 p. m.	16		120,000	Heavy hail	Principal loss in wheat; path 15 miles long.
Atmore, Ala., vicinity of.	30				2,000	Electrical	Mule killed by lightning and barn burned.
Carthage, Mo., and vicinity.	30				5,000	Wind	Crop loss; property damaged; \$5,000 estimated damage to a manufacturing plant.
Green County, Iowa	31	P. m.			10,000	Heavy rain, wind, and hail	Loss to crops because of flooding. In Jefferson, lightning struck a cable putting 75 telephones out of order. Near Churdan, 500 feet of railroad tracks washed out. Scores of houses, barns, and smaller buildings damaged by wind. Loss to crops, \$6,000; property damage, \$4,000.
Des Moines, Aimes, and Leon, Iowa	31					Electrical	2 residences and barns burned; damage to wires.
Taylor, Page, Union, Audubon, and Carroll Counties, Iowa	31					Heavy rain	Town of Brayton surrounded by water for several hours. Fields badly washed, necessitating much replanting of corn.

1 Miles instead of yards.
 2 From press reports.

Chart I. Departure (°F.) of the Mean Temperature from the Normal, May 1938



Shaded portions show excess (+)
Unshaded portions show deficiency (-)
Lines show amount of excess or deficiency

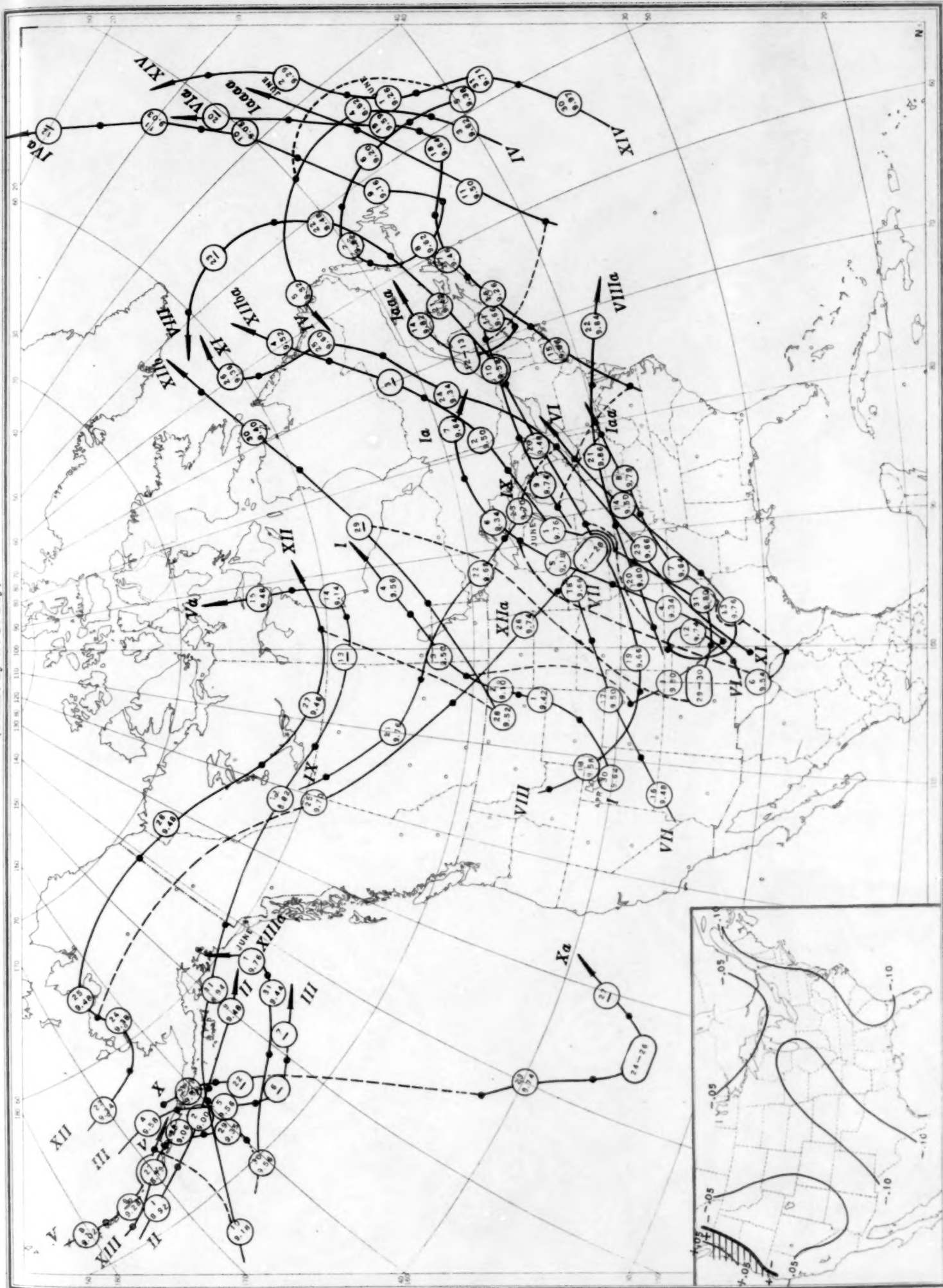
(Plotted by W. P. Day)



(Plotted by W. P. Day)

Circle indicates position of anticyclone at 7:30 a. m. (75th meridian time), with barometric reading. Dot indicates position of anticyclone at 7:30 p. m. (75th meridian time).

Chart III. Tracks of Centers of Cyclones, May 1938. (Inset) Change in Mean Pressure from Preceding Month (Plotted by W. P. Day)



Circle indicates position of cyclone at 7:30 a. m. (75th meridian time), with barometric reading. Dot indicates position of cyclone at 7:30 p. m. (75th meridian time).

Chart IV. Percentage of Clear Sky Between Sunrise and Sunset, May 1938

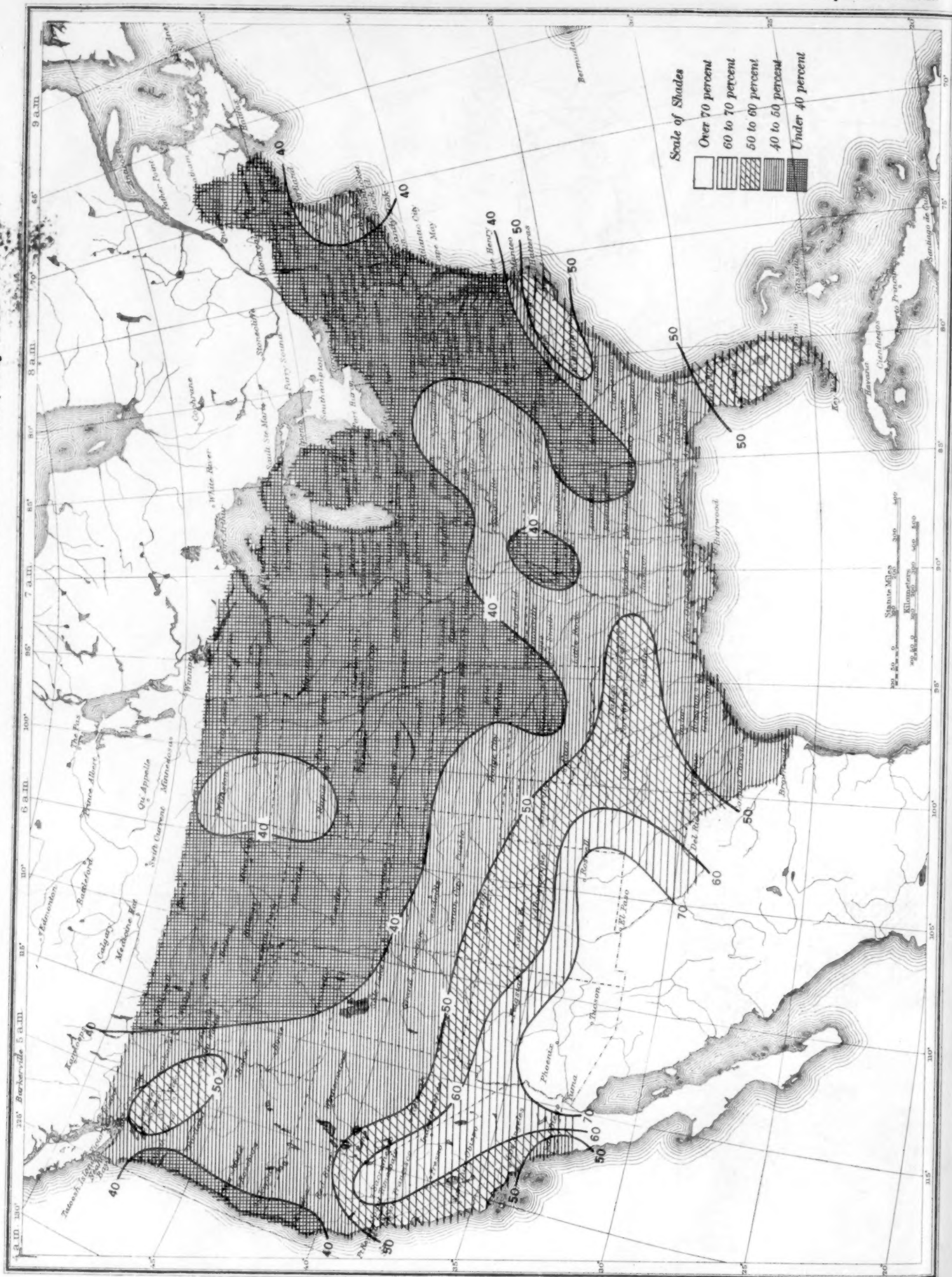


Chart V. Total Precipitation, Inches, May 1938. (Inset) Departure of Precipitation from Normal

Chart V. Total Precipitation, Inches, May 1938. (Inset) Departure of Precipitation from Normal

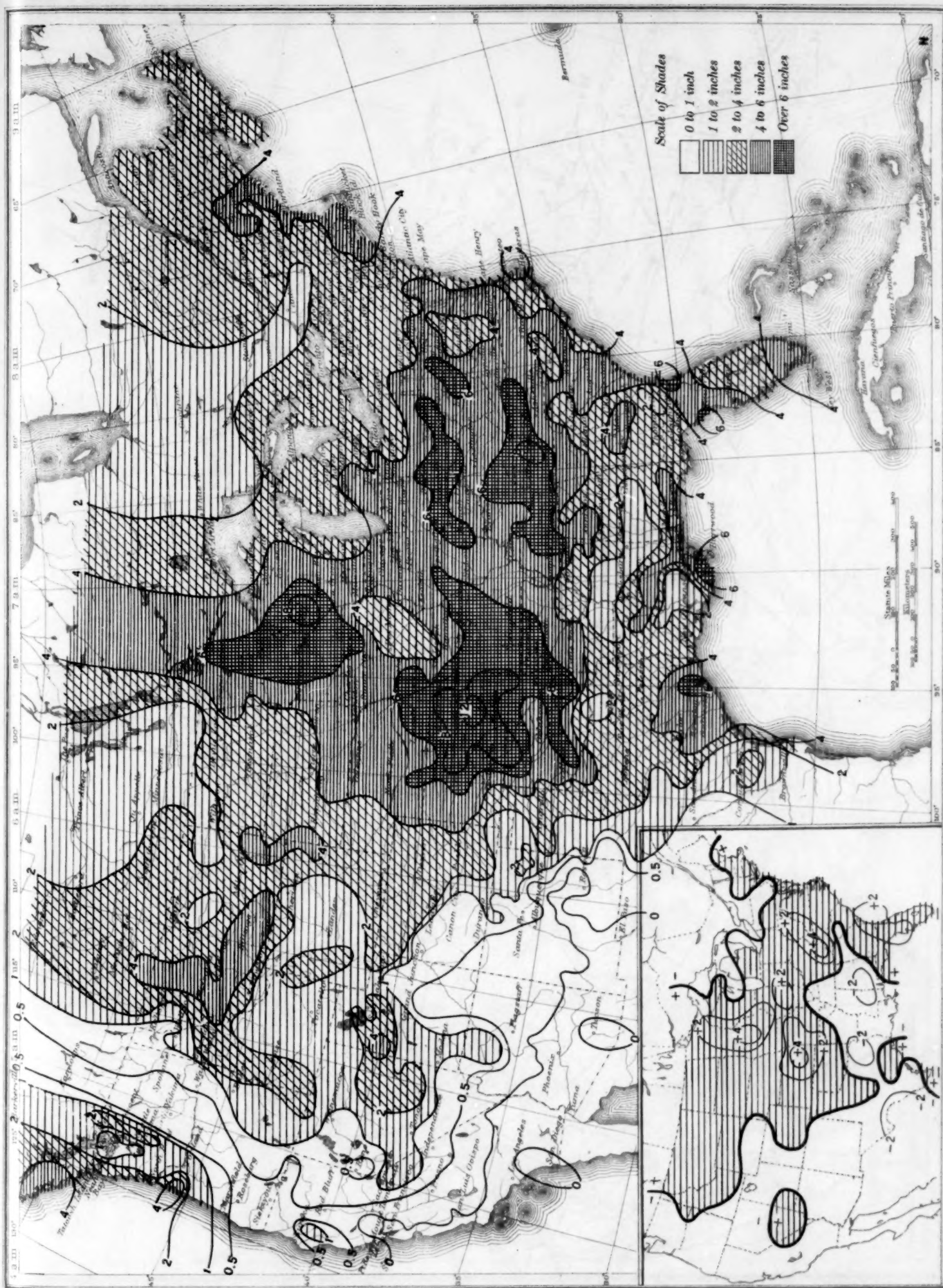


Chart VI. Isobars at Sea Level and Isotherms at Surface; Prevailing Winds, May 1938

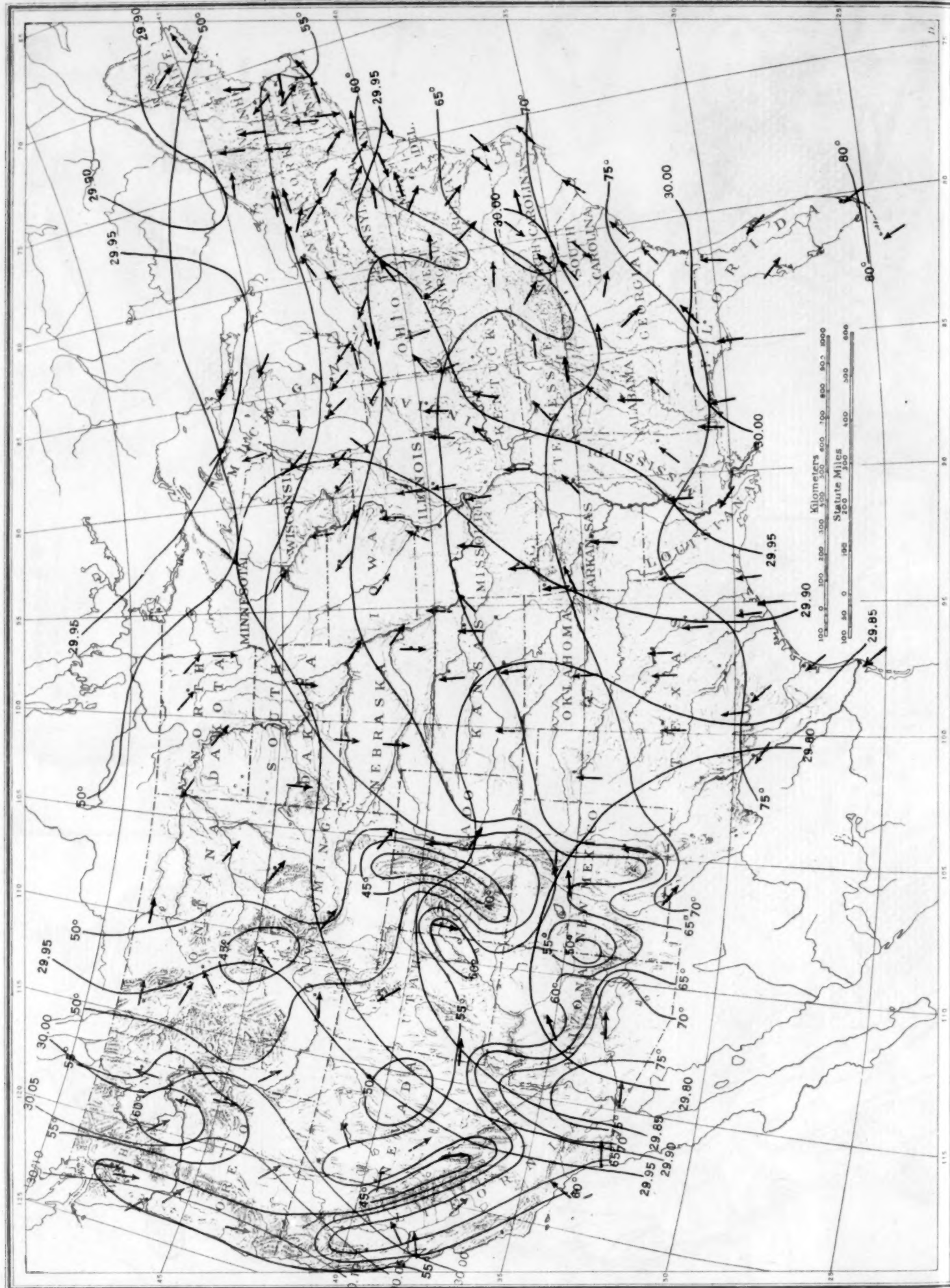


Chart VII. Wind Roses for Selected Stations, May 1938

(Plotted by W. W. Reed)

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(Plotted by W. W. Reed)

